Description of Module Master of Science 828 Photon Science and Technology

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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.

Explanations regarding the module catalogue

Preamble

The "Photon Science and Technology M.Sc." program is unique in Germany. For the first time, three universities from three different federal states are jointly conducting a study program to create top-level education in the emerging field of photonics through synergies and utilization of individual academic strengths. The Friedrich Schiller University Jena (FSU), the Friedrich Alexander University Erlangen-Nuremberg (FAU), and the Karlsruhe Institute of Technology (KIT) have been cooperating for years within the framework of the nationwide integrated graduate school "Max Planck School of Photonics" (MPSP). This program is aimed at the world's best and most suitable applicants, providing them with early orientation towards top-level research immediately after their bachelor's degree. To train students jointly and provide them with the best possible access to training opportunities at all three universities, this cooperative study program is established. For the most outstanding candidates, the new study program aims to enhance the attractiveness of Germany as a location, as individual excellence is underscored by operating a joint elite study program under cooperative responsibility.
The study program is research-oriented and focuses on acquiring research-relevant competencies. Students will learn within a cross-location network of the three universities. Central modules are taught jointly by lecturers from all three universities. The laboratory training involves all locations. In terms of specialization, students have access to the full range of research focuses pursued at the individual locations. The course of study is divided into three parts. The first semester is dedicated to acquiring subject-relevant basic competencies and aligning heterogeneous prior knowledge. The second and third semesters focus on specialization, imparting research-relevant competencies. The fourth semester concludes with the master's thesis as an independent scientific achievement.
The content is delivered in a balanced manner among the three universities. There are two modes of delivery. Firstly, in cooperative modules, lecturers from the three universities contribute equally to the joint teaching events. In the laboratory internships, responsibility rotates annually, and innovative remote lab approaches, specifically developed by MPSP in recent years and already operational, are also incorporated. Secondly, in the elective areas, all three universities offer an equal number of courses, providing students with access to the entire expertise of all three locations.

Structure and Organization of the Study Program

The study program comprises a total of 120 ECTS credits. Of these, 90 ECTS credits are earned in cooperative modules that are jointly managed by the three universities and include respective elements in student training. Additionally, there is an elective section where students can freely choose from the respective offerings of the three universities, utilizing their specific local strengths for their education. The cooperative modules of the first semester, "Introduction to Photon Science" and "IT and Research Methodology," are taught in a hybrid format by lecturers from all three universities, while the "Practical Training" module follows a rotation of locations for Block Practical Trainings in research laboratories. In the "Adjustment" compulsory elective section, students can select from the offerings of the three universities in close coordination with the central Student Coordination Office, tailored to their background and needs. The second and third semesters offer another compulsory elective section, "Fundamental Electives," where modules from the local offerings of the universities in the various specialization areas within Photonics can be taken. Of particular note is the two-semester comprehensive module "Specialization." Here, specialized lectures from the three universities' offerings are attended as courses, with selections closely coordinated with the Study Coordination Office to align with the students' developing research interests. This special module concludes with a colloquium at the end of the third semester, involving peers and faculty members from all three universities. In the cooperative module "Research Training," which also spans the second and third semesters, practical research skills are learned and practiced in two independent research groups at two different locations. Guidance is provided by a special graded research colloquium at the end of the first project, intended to assess the intermediate status of individual research methodologies and serve as planning for the second project. The study program concludes with the "Master's Thesis" module in the fourth semester, which must be defended before a panel of lecturers from all three universities.
The module catalog describes the modules and elective sections detailed here. For the latter, the module descriptions of the selectable modules from the respective universities are adopted and adapted from their local catalogs. The lectures that can be attended as courses within the "Specialization" module are also appended as adaptations from the local module catalogs.

Qualification Objective

The objective of the Master's program in Photon Science and Technology is to prepare students for research-oriented and scientifically-based careers in the fields of optics and optical technologies, or to provide the foundational academic training for advanced educational programs within or outside the university.
Graduates should acquire an in-depth knowledge of optics and optical technologies during their studies. This includes topics such as geometric optics, wave optics, electromagnetic theory, light propagation, polarization, interference, diffraction, Fourier optics, coherence theory, laser physics, and integrated photonics. Additionally, students gain comprehensive knowledge of the applications of optical technologies from both a physical and an engineering perspective. Beyond this general knowledge of the entire field of optics and optical technologies, students are expected to acquire specialized knowledge in chosen focus subjects and internships, enabling them to pursue further research-oriented education. Furthermore, students should acquire the qualification to present and discuss their own research work in presentations and scientific discussions at the current research level. The cross-location nature of the study program enables students to gain the competencies needed to navigate and organize themselves within a diverse research landscape and to choose the optimal qualification path for their personal development.

To achieve these qualification objectives, the program imparts progressive qualifications and competencies over both years of study:

a) In the first year of study, under the guiding themes of "Essentials," "Adjustment," and "Specialization," the following are taught:

- The fundamentals of modern knowledge in optics and photonics,
- The basics of advanced related fields in physics in preparation for specialization,
- The current state of research in selected areas,
- Advanced methodological and methodological competencies,
- Integrative thinking,
- The essential methods of experimentation in optics and photonics,
- Practical knowledge relevant to professional fields,
- Conceptual competencies for structuring research fields, applying theories to individual cases, and presenting results.

b) In the second year of study, under the guiding themes of "Specialization" and "Research Phase," the following are taught:

- Advanced knowledge in additional elective areas of optics and photonics with high relevance to current research,
- The implementation of theoretical, experimental, and methodological foundations in a theme-centered research project,
- The planning and execution of a research project,
- Systematic research work in a collective,
- The preparation of a scientific project report,
- Presentation of results and moderation.

Upon successful completion of the program, students will possess the professional and interdisciplinary key qualifications (including social competence and teamwork skills) required for a research-oriented and scientifically-based professional field. They will be capable of developing and implementing subject-specific research concepts. They will demonstrate the ability to critically assess scientific findings, think in an interdisciplinary manner, act responsibly, and analyze and develop solutions for complex scientific and technical issues across disciplines.

Acquisition of Interdisciplinary Competencies

The study program is designed to explicitly foster the acquisition of various competencies. The mandatory module "IT and Research Methodology" explicitly introduces the methods of scientific work. It includes the following:

- Standard steps of scientific work
- Quality criteria for good scientific practice
- Research data management
- Software for scientific practice (citation software, etc.)
- Laboratory automation
- Programming techniques
- Competency in self-learning with online resources

The module "Practical Training" deepens not only subject-specific aspects but also competencies in laboratory management and automation. A distinctive feature is the completion of this module at two locations, allowing students to experience the focuses and specificities of both sites.
The modules "Research Training" and "Master’s Thesis" involve intensive, research-related activities. All competencies related to scientific work are further trained and deepened, with a strong emphasis on adhering to the criteria for good scientific practice. Additionally, the writing of scientific reports and papers is intensively practiced.
In the modules "Specialization," "Research Training," and "Master’s Thesis," extensive presentations are mandatory. To systematically prepare for this, mandatory training sessions are offered in the Spring and Autumn Schools.
Through participation in courses taught by lecturers from different study locations and in joint responsibility, students learn perspectives arising from different traditions and focuses, significantly enhancing their ability to adopt different viewpoints and their cognitive flexibility.
In internships completed at various study locations, the interaction with different actors and scientific cultures is further practiced.
Naturally, an international study program supports intercultural encounters in various ways. Intercultural aspects are continuously addressed and processed in study counseling and reflection sessions offered in the Spring and Autumn Schools.
Working at different study locations promotes and develops the ability to work independently and adaptively, as well as self-organization.
In the Spring and Autumn Schools, external lecturers impart important key qualifications (self-management, communication, etc.).
Lecturers from the industry facilitate orientation within this potential future work environment.

Relationship of Qualification Objectives at Program and Module Levels

The central qualification objective is to equip students with the competence for independent scientific work in the field of photonics at a high international level. This competence requires highly developed theoretical and methodological knowledge as well as their application through actual research activities.
The modules are systematically structured to build upon each other. In the first semester, the modules "Introduction to Photon Science," "Adjustment," "IT and Research Methodology," and "Practical Training" lay the critical theoretical and methodological foundations. The explicit module "IT and Research Methodology" ensures that these important cross-sectional qualifications are acquired explicitly and reflectively.

The foundations laid in the first semester are deepened in the modules "Fundamental Electives" and "Specialization." These modules build on the basics, delve deeper into selected content areas, and prepare students for the "Master’s Thesis." The concurrent module "Research Training" provides a specific interface to the final "Master’s Thesis," as it translates the theoretical deepening into applied research activity. Continuous academic advising ensures a coherent combination of courses and research projects in the second and third semesters, which are also meaningfully related to the subsequent "Master’s Thesis."
The final "Master’s Thesis" integrates all previously acquired competencies.
Continuous academic advising, along with the Spring School and Autumn School, reflects on and consolidates the competency acquisition, making adjustments as necessary.

Modul **CORE-IN-01** Introduction to Photon Science	
Module code	CORE-IN-01
Module title (German)	Introduction to Photon Science
Module title (English)	Introduction to Photon Science
Person responsible for the module	N. Joly (FAU), I. Staude (FSU), C. Rockstuhl (KIT)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: compulsory
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	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h
Content	The module consists of a single course titled "Fundamentals of Photon Science." This comprehensive course covers all essential topics of optics and photonics, supplemented with experimental demonstrations. The goal is to both illustrate as well as to help the students develop a solid theoretical as well as an intuitive understanding of the key concepts. The course takes place exclusively as an online lecture to accommodate both the students and the lecturers from all participating universities, as well as to enable networking within the student cohort.
Intended learning outcomes	The students will have established a knowledge of basic optics and photonics. They will comprehend the physics of optical phenomena and their application in simple optical components. The students will have learnt how to describe laws of physics in a mathematical form and how to verify these laws in experiments in addition to being trained to solve problems in basic and applied optics and photonics.

Prerequisites for admission to the module examination	The students hand in solutions to an assignment as homework once a week. An overall amount of 50% of the problems must be solved correctly. Additionally, active participation in the exercises including at least one presentation of solutions of a homework problem is required to qualify for the written exam
Requirements for awarding credit points (type of examination)	Written examination (60, 90 or 120 mins) **Grading:** Based on the performance in the written examination.
Additional information on the module	Educators from all three universities offer the course in equal parts including lectures and seminars. All partners agree upon a joint course program with balanced individual contributions. This course program includes contents for lectures, exercises and examinations. In practice, this is realized by splitting the course into three equal parts that are each attributed to an educator from each location. Each part is taught online to the entire cohort of students. The responsibility for the primary organization is rotated annually among the three universities.
Recommended reading	--
Language of instruction	English

Modul **CORE-IT-01** IT and Research Methodology	
Module code	CORE-IT-01
Module title (German)	Informationstechnische Methoden der modernen Forschung
Module title (English)	IT and Research Methodology
Person responsible for the module	B. Schmauss (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: compulsory
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	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	This module conveys competence in using information technology and resources. The course captures the following aspects: • Programming skills in a generic and ubiquitously used language such as Python or C++. • Essential aspects of lab-automation to mirror the needs of a solid education to information aspects not just in theoretical and numerical science but also in experimental science. • Outlining the most important aspects of online learning and, in perspective, also teaching, the use of AI etc. • Introduction to Good Scientific Practice. • Research Data Management. • The use of tools to work in the scientific world, particularly in a partially online environment.

Intended learning outcomes	Students completing the IT and Research Methodology module should be able to evaluate and to use the basic general methods, which are essential to conduct research in an academic environment. Besides enabling efficient research, the module should also provide the ground for quality control in research and create awareness of the limits of good scientific practice.
Prerequisites for admission to the module examination	The students must solve given problems and actively participate in the exercises. At least one presentation of solutions of a homework problem is required to qualify for the examination.
Requirements for awarding credit points (type of examination)	**Type of Examination:** written (60, 90, or 120 mins) or oral examination (30, 45, or 60 mins) **Grading:** from examination result.
Additional information on the module	Educators from all three teaching universities offer the course in equal parts including lectures and seminars. All partners agree upon a joint course program with balanced individual contributions. This course program includes contents for lectures and seminars as well as exercises and examinations. In practice, this could be realized by splitting the course in three equal parts that are each attributed to an educator from each location. Each part is taught online to the entire cohort of students. If necessary, one of the three teaching universities takes primary responsibility while the other partners support the module in equal parts. The responsibilities for the individual teaching universities along with any additional teaching load are limited by virtue of an annual rotation.
Recommended reading	--
Language of instruction	Englisch

Modul **CORE-PT-01** Practical Training	
Module code	CORE-PT-01
Module title (German)	Praktische Ausbildung
Module title (English)	Practical Training
Person responsible for the module	S. Nolte (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: compulsory
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, ...)	6 experimentation sessions with a duration of 5 hours
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 30 h 120 h
Content	The students conduct the experiments on-site in a laboratory. These experiments are complemented by dedicated virtual environments and Remote Lab Experiments as offered by the MPSP and its Digital Teaching Lab. The purpose is to provide hands-on training on many optical technologies and expose the students at that early stage to different experimental techniques, including numerical experiments
Intended learning outcomes	The students learn how to prepare and carry out experiments on optics and photonics, analyze the obtained data, and summarize and discuss their results in a scientific report. In parallel, the students will obtain knowledge on state-of-the-art experimental instruments and methods.
Prerequisites for admission to the module examination	
Requirements for awarding credit points (type of examination)	Type of Examination: - Grading: pass / no pass

Additional information on the module	The teaching universities organize the course at one of the three locations. All students of the Collaborative Master's program participate in it together. The course takes place after the examination period of the first semester has ended. In this optics and photonics lab course, the students choose according to their interests among multiple optics experiments that are offered. In groups of two or three, students carry out experiments according to their preferences. The composition of the groups changes with each rotation. Educators from all three teaching universities offer the course in equal parts. All partners agree upon a joint course program with balanced individual contributions. This course program includes access to and supervision of optical training experiments and numerical experiments. The majority of basic training experiments is available at all three sites allowing for consistent education across cohorts. If necessary, one of the three teaching universities takes primary responsibility while the other partners support the module in equal parts. The responsibilities for the individual teaching universities along with any additional teaching load are limited by virtue of an annual rotation.
Language of instruction	English

Modul **CORE-RT-01** Research Training	
Module code	CORE-RT-01
Module title (German)	Research Training
Module title (English)	Research Training
Person responsible for the module	C. Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: compulsory
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Practical labwork and seminar.
ECTS credits	20 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	600 h - h - h
Content	The student chooses two research projects in two different research groups in the 2nd and 3rd semester. Depending on the topic the total workload of 300h per project 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 or theoretically / numerically) • 50 h preparation of the final report • 10 h preparation and carrying out presentation of the resultsAfter the completion of the first project with a written report (ungraded), there is a graded presentation seminar at the MPSP Autumn School, addressing the skills to present the own research orally. Acquired research skills are presented and relevant skills to acquire with the second project are identified. For the second project, the written report is graded, which addresses the skill to present own research in a written way as preparation for the Master's Thesis.
Intended learning outcomes	The students learn how to independently prepare and carry out advanced experiments, analyze the obtained data as well as how to summarize and discuss their results in written and oral scientific reports.
Prerequisites for admission to the module examination	Written report on first research project and presentation of second research project

Requirements for awarding credit points (type of examination)	Type of Examination: Seminar presentation of first research project and written report on second presentation Grading: Average of the grades for the presentation and the written report.
Additional information on the module	The students are working on research projects in different labs.
Language of instruction	English

Modul **CORE-SP-01** Specialization	
Module code	CORE-SP-01
Module title (German)	Spezialisation
Module title (English)	Specialization
Person responsible for the module	I. Staude (FSU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	--
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	MSc. Photon Science and Technology: compulsory
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, ...)	Lectures, exercises and seminar
ECTS credits	20 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	600 h - h - h
Content	The module consists of two parts. In the first part, the students select courses depending on their individual interest to acquire specialized knowledge in Photonics. They must successfully complete courses with a workload equivalent to at least 20 ECTS credits. In the second part, students have to successfully complete a presentation at the end of the third semester. This consists of a poster presentation seminar at the MPSP Spring School about the individual specialization path and projects. We list individual courses, which can be taken to successfully complete this module in the appendix. It is possible to acknowledge further courses upon decision of the module coordinator.

Intended learning outcomes	Depending on the field of specialization chosen, the following learning outcomes are intended. • **Biophotonics:** Modern methods in spectroscopy, microscopy and imaging dedicated to biological samples are presented. Students understand the working principles of modern light microscopes and microscopic methods ranging from standard methods to modern superresolution techniques. The students will be able to choose and apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonic problems. • **Nano- and Microoptics:** The student learns the basics of integrated and diffractive optics. The student is familiar with the broad research field of nanooptics, where they learn about different concepts applied to control the emission, propagation, and absorption of light at subwavelength spatial dimensions. The students have an overview and understanding of the common technologies and their limitations for the fabrication of optical micro- and nanostructures. • **Photonics System Design:** Students learn about the layout, performance analysis, and optimization of optical systems. They learn fundamental concepts needed to develop and design lasers. In addition, they gain knowledge on concepts and structures of optical systems and can design and optimize these systems. • **Strong-field Physics:** Students are familiar with basic concepts and techniques in physics related to extreme electromagnetic fields, strong-field physics, including ultrafast physics and laser-driven particle acceleration. Experimental methods and related theoretical descriptions will be reviewed in detail. • **X-ray Science:** The students know the relevance of X-ray optics in science and material analysis. They can describe the basic phenomena of X-ray generation, propagation, and detection and can calculate the optical path X-rays will follow. In addition, students are familiar with different types of X-ray optical systems. • **Quantum Optics:** The students comprehend the physics of quantum optical phenomena, the necessary theoretical means for their description, and the application of quantum optical resources in different applications and technologies. They learn how to express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum optical phenomena in specific situations. The course provides training to solve basic problems in quantum optics.
Prerequisites for admission to the module examination	According to the individual courses

Requirements for awarding credit points (type of examination)	Successful completion of courses equivalent to a workload of 20 ECTS credits and passing of module examination. Type of Examination: EITHER volunteering to take the individually offered course examinations OR taking an overarching examination (written, 180mins) at the end of the 3rd semester. The presentation is judged by an advisory committee. The committee consists of three educators of each teaching university. During the module examination, the student discusses lecture contents and project results with the committee. The presentation is graded as ”passed” or ”not passed”. Grading: EITHER the average of all creditable voluntary examination results weighted by the respective workload of the courses (ECTS equivalent) OR the result of the overarching examination.
Recommended reading	--
Language of instruction	English

Modul **FAU-42135** Image Processing in Optical Nanoscopy	
Module code	FAU-42135
Module title (German)	Image Processing in Optical Nanoscopy
Module title (English)	Image Processing in Optical Nanoscopy
Person responsible for the module	Prof. Dr. Harald Köstler (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	The module includes two interlinked topics. First, an introduction to the techniques of optical imaging (e.g. for biological specimen) with a special focus on recently evolving super-resolution techniques beyond the diffraction barrier. Second, the students will be given an overview of existing numerical techniques in imaging processing, especially for image deblurring. The focus lies on algorithms based on sparse coding and deep learning methods. Additionally, one makes use of information about the imaging system. The algorithms are applied to optical imaging and implemented in Matlab or Python.
Intended learning outcomes	• Students are able to implement image processing algorithms in Matlab. • They can differentiate between different methods of high-resolution microscopy. • They can validate image processing algorithms on real data.
Prerequisites for admission to the module examination	--

Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-42140** Optical Lithography: Technology, Physical Effects and Modeling	
Module code	FAU-42140
Module title (German)	Optical Lithography: Technology, Physical Effects and Modeling
Module title (English)	Optical Lithography: Technology, Physical Effects and Modeling
Person responsible for the module	PD Dr. Andreas Erdmann (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	Semiconductor lithography covers the process of pattern transfer from a mask/layout to a photosensitive layer on the surface of a wafer. It is one of the most critical steps in the fabrication of microelectronic circuits. The majority of semiconductor chips are fabricated by optical projection lithography. Other lithographic techniques are used to fabricate lithographic masks or new optical and mechanical devices on the micro- or nanometer scale. Innovations such as the introduction of optical proximity correction OPC), phase shift masks (PSM), special illumination techniques, chemical amplified resist (CAR) materials, immersion techniques have pushed the smallest feature sizes, which are produced by optical projection techniques, from several wavelengths in the early 80ties to less than a quarter of a wavelength nowadays. This course reviews different types of optical lithographies and compares them to other methods. The advantages, disadvantages, and limitations of lithographic methods are dis-cussed from different perspectives. Important components of lithographic systems, such as masks, projection systems, and photoresist will be described in detail. Physical and chemical effects such as the light diffraction from small features on advanced photomasks, image formation in high numerical aperture systems, and coupled kinetic/ diffusion processes in modern chemical amplified resists will be analysed. The course includes an in- depth introduction to lithography simulation which is used to devise and optimize modern lithographic processes.
Intended learning outcomes	The students understand the principles of optical projection lithography learn how optical resolution enhancements work get an overview on alternative lithographic techniques get an introduction to lithography simulation understand the role of nanoscale light scattering effects.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	• C. Mack: "Fundamental principles of optical lithography: The science of microfabrication", John Wiley & Sons, 2007. • O. Okoroanyanwu: "Chemistry and Lithography", SPIE press 2012. • H.J. Levinson: "Principles of lithography, SPIE Press, 2011. • A. Erdmann, T. Fuehner, P. Evanschitzky, V. Agudelo, C. Freund, P. Michalak, D. Xu: Optical and EUV projection lithography: A computational view (invited for 30 years special edition), Microelectronic Engineering 132 (2015) 21-34.
Language of instruction	English

Modul **FAU-42155** Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics	
Module code	FAU-42155
Module title (German)	Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics
Module title (English)	Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics
Person responsible for the module	Prof. Dr. Joachim Zanthier (FAU) Prof. Dr. Stephan Götzinger (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
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: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (4 SWS) Exercise: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (2 SWS)
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h

Content	**Introduction:** Fundamental Properties and working scheme of the Laser, applications **Optical resonators:** Ray transfer matrix analysis, stability criteria for optical resonators **Propagation of waves in optical media:** Solutions to the wave equation, complex index of refraction, dispersion **Gaussian beams:** Solution of the paraxial wave equation, Gaussian beams of higher order, properties of Gaussian beams, Gaussian beams and resonators, resonators as interferometer and spectrometer **Light-matter interaction:** Classical description, semiclassical description, stimulated emission, black body radiation, interaction of a two-level atom with a monochromatic wave **Theory of the laser:** Maxwell-Bloch-equations, laser operation in equilibrium, rate equations, outcoupled laser power, relaxation oscillations, micro-lasers, laser noise (Schawlow-Townes-Limit), generation and measurement of ultrashort pulses **Laser systems:** Gas lasers, solid state lasers, vibronic lasers, laser frequency analysis and stabilization **Laser spectroscopy:** Spectral lines + -profiles, broadening mechanisms, doppler-free spectroscopy **Cooling and trapping of atoms:** Doppler cooling, magneto-otical trap, trapping of single atoms, Bose-Einstein-condensation
Intended learning outcomes	Students • explain and analyze advanced topics of lasers, atomic physics and quantum optics as outlined in the table of contents • apply the associated physical concepts to specific problems using appropriate methods
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-42935** Optical diagnostics in energy and process engineering	
Module code	FAU-42935
Module title (German)	Optical diagnostics in energy and process engineering
Module title (English)	Optical diagnostics in energy and process engineering
Person responsible for the module	Simon Aßmann (FAU) Dr.-Ing. Franz Huber (FAU) Prof. Dr.-Ing. Stefan Will (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	Introduction to conventional and novel optical techniques to measure state and process functions in thermodynamical systems: • Properties of light; properties of molecules; Boltzmann distribution • Geometric optics and optical devices • Lasers (HeNe, Nd:YAG, dye, frequency conversion); continuous wave and pulsed lasers • Photoelectric effect; photodetectors (photomultiplier, photodiode, CCD, CMOS, image intensifier); digital image processing; image noise and resolution • Shadowgraphy and Schlieren techniques (flow and mixing) • Elastic light scattering (Mie scattering, Rayleigh thermometry, nanoparticle size and shape, droplet sizing) • Raman scattering (species concentration, temperature, diffusion) • Incandescence (thermal radiation, temperature fields, pyrometry, particle sizing) • Velocimetry (flow fields, velocity) • Absorption (temperature, pressure, species, concentration) • Fluorescence and phosphorescence (temperature, species, concentration)
Intended learning outcomes	Students gain technical and technological skills in the field of optical techniques for the measurement of state and process variables in thermodynamic / energy processes and the investigation of these processes. They • are familiar with the state of the art and latest developments in optical measurement techniques applied in thermodynamics / energy processes • can assess the applicability of measurement techniques in different environments • can apply different optical measurement techniques in thermodynamic processes and design experiments • can evaluate data gained from optical measurement techniques and assess the quality of data • know interdisciplinary approaches in the fields of optics, thermodynamics, heat and mass transfer and fluid mechanics • are qualified to perform applied and fundamental research and development tasks in industry and at university in the field of optical measurement techniques for thermodynamic / energy processes
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	Lecture Slides Bräuer, Andreas: In situ Spectroscopic Techniques at High Pressure, Amsterdam 2015
Language of instruction	English

Modul **FAU-43220** Computational Optics	
Module code	FAU-43220
Module title (German)	Computational Optics
Module title (English)	Computational Optics
Person responsible for the module	Prof. Dr. Christoph Pflaum (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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 with exercises: Computational Optics CE & MAOT (2+2 SWS)
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	• Simulation of Optical Waves • Finite-Difference Method for Solving Maxwell's Equations • Beam Propagation Methods • Rate Equations for Photons • Application in the Simulation of Lasers and Thin-Film Solar Cells
Intended learning outcomes	Students will be able to: 1) **Explain the fundamental principles** underlying the simulation of optical wave phenomena and their relevance in modern photonics. 2) **Apply the finite-difference method** to numerically solve Maxwell's equations in the context of optical wave propagation. 3) **Utilize beam propagation methods (BPM)** to model and analyze guided-wave and free-space optical systems. 4) **Formulate and solve photon rate equations** for the simulation of light–matter interaction in optoelectronic devices. 5) **Develop and implement computational models** for simulating the performance of lasers and thin-film solar cells. 6) **Critically assess simulation results** and validate them against physical models and empirical data.

Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	60 min written exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-43386** Computational Photography and Capture	
Module code	FAU-43386
Module title (German)	Computational Photography and Capture
Module title (English)	Computational Photography and Capture
Person responsible for the module	Prof. Dr. Tim Weyrich (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	Never in human history have we been able to record so much of our environment in so little time with such high quality. Since the rise of smartphones, nearly everyone carries a powerful camera with them in their daily lives. This module introduces the theoretical and practical aspects of modern photography and capture algorithms: universal models of colour, computer-controlled cameras, lighting and shape capture. The lecture covers the following topics: • Cameras, sensors and colour • Image processing (e.g., blending, warping) • Radiometry • Appearance acquisition • Structured-light 3D acquisition • Image-based and video-based rendering

Intended learning outcomes	The students: • understand the basic vocabulary of computational photography • grasp the principles of light transport in natural scenes and digital image formation • can explain how computational photography algorithms enhance traditional imaging techniques • are familiar with image-processing algorithms for analyzing and transforming images • can apply acquisition algorithms to capture appearances and reconstruct 3D scenes • are able to develop their own software prototypes for capturing and processing digital images
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-44120** Pattern Analysis	
Module code	FAU-44120
Module title (German)	Pattern Analysis
Module title (English)	Pattern Analysis
Person responsible for the module	PD Dr.Ing. Christian Riess (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 3 SWS and exercise 1 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods. The topics comprise: • clustering methods: soft and hard clustering • classification and regression trees and forests • parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees • mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking • linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps • Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling • Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts
Intended learning outcomes	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies, • implement presented methods in Python, • supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of pattern analysis solutions.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	60 min written exam
Additional information on the module	--

Recommended reading	C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013
Language of instruction	English

Modul **FAU-44141** Medical Image Processing for Interventional Applications	
Module code	FAU-44141
Module title (German)	Medical Image Processing for Interventional Applications
Module title (English)	Medical Image Processing for Interventional Applications
Person responsible for the module	Prof. Dr.-Ing. Andreas Maier (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	None
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 4 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	This module focuses on recent developments in image processing driven by medical applications. All algorithms are motivated by practical problems. The mathematical tools required to solve the considered image processing tasks will be introduced. The module starts with an overview on preprocessing algorithms such as scatter correction for x-ray images, edge detection, super-resolution and edge-preserving noise reduction. The second chapter describes automatic image analysis using feature descriptors, key point detection, and segmentation using bottom-up algorithms such as the random walker or top-down approaches such as active shape models. Furthermore, the module covers geometric calibration algorithms for single view calibration, epipolar geometry, and factorization. The last part of the module covers non-rigid registration based on variational methods and motion-compensated image reconstruction.

Intended learning outcomes	The participants: • summarize the contents of the lecture. • apply pre-processing algorithms such as scatter correction and edge-preserving filtering. • extract information from images automatically by image analysis methods such as key point detectors and segmentation algorithms. • calibrate projection geometries for single images and image sequences using the described methods. • develop non-rigid registration methods using variational calculus and different regularizers. • adopt algorithms to new domains by appropriate modifications.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-44151** Medical Image Processing for Diagnostic Applications	
Module code	FAU-44151
Module title (German)	Medical Image Processing for Diagnostic Applications
Module title (English)	Medical Image Processing for Diagnostic Applications
Person responsible for the module	Prof. Dr.-Ing. Andreas Maier (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 4 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	The contents of the module comprise basics about medical imaging modalities and acquisition hardware. Furthermore, details on acquisition-dependent preprocessing are covered for image intensifiers, flat-panel detectors, and MR. The fundamentals of 3D reconstruction from parallel-beam to cone-beam reconstruction are also covered. In the last chapter, rigid registration for image fusion is explained.
Intended learning outcomes	The participants • understand the challenges in interdisciplinary work between engineers and medical practitioners. • develop understanding of algorithms and math for diagnostic medical image processing. • learn that creative adaptation of known algorithms to new problems is key for their future career. • develop the ability to adapt algorithms to different problems. • are able to explain algorithms and concepts of the module to other engineers.
Prerequisites for admission to the module examination	--

Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-45730** Optical Technologies in Life Science	
Module code	FAU-45730
Module title (German)	Optical Technologies in Life Science
Module title (English)	Optical Technologies in Life Science
Person responsible for the module	PD Dr.habil. Sebastian Schürmann (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 and exercise 4 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	• Application of optical methods in the field of cell biology and medicine • Microscopy: Basic concepts, methods to enhance contrast, optical resolution and limits, components and setup of light microscopes, fluorescence microscopy • Applications of fluorescence microscopy in life sciences, methods for labeling of biological structures and cellular processes • Epi-fluorescence, confocal and multiphoton microscopy, concepts and application examples • Optical endoscopy and endomicroscopy in research and clinics • Super-resolution microscopy, concepts and applications for optical Imaging beyond the diffraction Limit of Resolution

Intended learning outcomes	Students • understand the basic concepts and specific technical approaches to optical technologies in life sciences and identify typical applications examples. • can analyze and compare different technical approaches to scientific research questions. • can summarize advantages and disadvantages of different technologies and assess theoretical and practical limitations with regard to experimental approaches and results. • can find, collect and structure in-depth information on technical solutions, materials and methods in the areas of microscopy and spectroscopy, in order to plan scientific experiments.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	• Michael W. Davidson et al: Microscopy Primer, https://micro.magnet.fsu.edu/, umfassendes Online-Lehrwerk über grundlegende Mikroskopieverfahren und neuesten technischen Entwicklungen • Bruce Alberts: Molecular Biology of the Cell, 4th Edition, New York, Garland Science Publisher. Standardlehrwerk für die Zellbiologie. • Ulrich Kubitschek: Fluorescence Microscopy: from Principles to Biological Applications, Wiley-VCH Verlag. • Douglas Chandler & Robert Roberson: Bioimaging: Current Concepts in Light and Electron Microscopy, Jones and Bartlett Publishers.
Language of instruction	English

Modul **FAU-48313** Modern Optics 3: Quantum Optics	
Module code	FAU-48313
Module title (German)	Modern Optics 3: Quantum Optics
Module title (English)	Modern Optics 3: Quantum Optics
Person responsible for the module	Prof. Dr. Maria Chekhova (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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: Modern Optics 3: Quantum Optics (2 SWS)
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	Contents: • Basic concepts of statistical optics • Spatial and temporal coherence. Coherent modes, photon number per mode • Intensity fluctuations and Hanbury Brown and Twiss experiment • Interaction between atom and light (semiclassical description) • Quantization of the electromagnetic field • Quantum operators and quantum states • Heisenberg and Schrödinger pictures • Polarization in quantum optics • Nonlinear optical effects for producing nonclassical light • Parametric down-conversion and four-wave mixing, biphotons, squeezed light • Single-photon states and single-photon emitters • Entanglement and Bells inequality violation

Intended learning outcomes	Learning goals and competences: Students • explain the relevant topics of the lecture • apply the methods to specific examples
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-582360** Modern Optics 2: Nonlinear Optics	
Module code	FAU-582360
Module title (German)	Modern Optics 2: Nonlinear Optics
Module title (English)	Modern Optics 2: Nonlinear Optics
Person responsible for the module	Prof. Dr. Nicolas Joly (FAU)
Prerequisites for admission to the module	--
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	• Linear properties of materials. • Origin of the nonlinear susceptibility. • Importance of phase-matching. • Second harmonic generation, derivation of the set of coupled equations. • Importance of the initial phase and case of seeding second harmonic generation. Use of birefringence to achieve phase-matching. • Electro-optic effects. • Nonlinear process in relation to third order nonlinearity. • Modulation instability, soliton formation, perturbations of soliton, and supercontinuum generation. • Application: nonlinear optics in photonic crystal fibers.

Intended learning outcomes	The students • understand linear and nonlinear optical properties of materials • can explain the origin of nonlinear susceptibility and the role of phase-matching • are able to derive and analyze coupled equations for second harmonic generation understand electro-optic effects and third-order nonlinearities • can describe modulation instability, soliton dynamics, and supercontinuum generation • are familiar with nonlinear optical processes in photonic crystal fibers and their applications
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	• Paul Mandel : Nonlinear Optics (Wiley-VCH 2010) • Robert Boyd: Nonlinear Optics (Academic Press, 2008) • Geoffrey New: Introduction to nonlinear optics (Cambridge University Press, 2011)
Language of instruction	English

Modul **FAU-621649** Advanced optical communication systems	
Module code	FAU-621649
Module title (German)	Advanced optical communication systems
Module title (English)	Advanced optical communication systems
Person responsible for the module	Prof. Dr.-Ing. Bernhard Schmauß (FAU) Lisa-Sophie Härteis (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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:** Advanced Optical Communication Systems (2 SWS) **Exercises:** Advanced Optical Communication Systems (2 SWS)
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	• Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats:intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration

Intended learning outcomes	Students • gain detailed Knowledge on concepts and structure of various optical transmission systems. • are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. • are able to develop and to optimize link designes of optical transmission systems. • are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	• Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997 • Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. • Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. • Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008. • Lecture notes.
Language of instruction	English

Modul **FAU-66961** Advanced theoretical physics	
Module code	FAU-66961
Module title (German)	Advanced theoretical physics
Module title (English)	Advanced theoretical physics
Person responsible for the module	Prof. Dr. Kristina Giesel (FAU) Prof. Dr. Hanno Sahlmann (FAU) Prof. Dr. Ana-Suncana Smith (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
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, ...)	**either** Lecture: Advanced theoretical physics: Advanced quantum mechanics (4 SWS) Exercise class: Advanced theoretical physics: Advanced quantum mechanics (3 SWS) **Or else** Lecture: Advanced theoretical physics: Solid state physics (4 SWS) Exercise class: Advanced theoretical physics: Solid state physics (3 SWS)
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 105 h 95 h

Content	**Course Advanced Quantum Mechanics (TV-A):** The course covers an introduction to quantum field theory. The following main topics will be discussed in the lecture: • Motivation Quantum Field Theory • Classical Field Theory (Hamiltonian, Lagrange formalism for classical field theories) • Relativistic Quantum Mechanics (Klein-Gordon and Dirac equation) • Representation Theory Lorentz- und Poincare-Groups (finite dimensional scalar-, vector, tensor and spinor representations of the Lorentz group, infinite dimensional representations: field representations, finite and infinite dimensional representation of the Poincare group) • Quantisation of Free Fields (multi particle states, Fock space, canonical quantisation of scalar, vector and spinor fields) • Quantisation of Interacting Field Theories (interaction picture, Dyson series, perturbation theory, S-matrix, Feynman rules, Higgs Mechanism) **Course Advanced Solid State Physics (TV-B):** The following main topics will be discussed in this course: • Structure of solids: Bravais lattices, reciprocal lattice, Brillouin zone • The solid as a many-body problem: Hamiltonian of a solid, electron-electron interaction, electron-ion interaction, separation of electronic and ionic motion (Born-Oppenheimer approximation), types of bonding • Lattice dynamics: Phonons: Harmonic approximation, classical solution, dispersion relation, acoustic and optical modes, Debye and Einstein model, quantum theory of lattice vibrations, phonons, density of states, van Hove singularities, hermal properties, anharmonic effects • Electrons in a periodic potential: Bloch theorem, band structure, nearly free electrons, tight-binding method, Wannier functions, metals, insulators, semiconductors, density of states, Fermi surface, quantum statistics, thermal properties, Fermi distribution • Electron-electron interaction: Hartree-Fock method, density functional theory, homogeneous electron gas • Topics of current research
Intended learning outcomes	**Course Advanced Quantum Mechanics (TV-A):** Students • comprehend, outline and explain classical and quantum field theory, as well as relativistic quantum mechanics • apply the methods of advanced quantum mechanics to specific problems **Course Advanced Solid State Physics (TV-B):** Students • comprehend, outline and explain the theory of structure and many-body properties of solids, phonons, electrons in a periodic potential and their interaction as well as transport theory • apply the methods of advanced theoretical solid-state physics to specific problems

Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-67009** Novel techniques in ultrafast spectroscopy	
Module code	FAU-67009
Module title (German)	Novel techniques in ultrafast spectroscopy
Module title (English)	Novel techniques in ultrafast spectroscopy
Person responsible for the module	Prof. Dr. Daniele Fausti (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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, ...)	Seminar 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	Review of recently developed techniques for the characterization of the dynamical response of complex materials: • Single and multipartite dynamics in non-linear spectroscopy https://www.nature.com/articles/s41586-023-05846-7 • Two dimensional optical spectroscopy https://onlinelibrary.wiley.com/doi/full/10.1002/andp.201300153 • Two dimensional broadband electronic spectroscopy https://pubs.acs.org/doi/abs/10.1021/acs.chemrev.1c00623 • Driving complex matter with mid-IR pulses Phonon pump https://www.nature.com/articles/nphys2055 • Ultrafast x-ray probes of dynamics in solids https://arxiv.org/abs/2108.05456 • Ultrafast electron probe of dynamics in solid https://www.science.org/doi/10.1126/science.1090052 • Ultrafast X-ray imaging of the light-induced phase transition in VO2 https://www.nature.com/articles/s41567-022-01848-w • Subcycle contact-free nanoscopy of ultrafast interlayer transport in atomically thin heterostructures https://www.nature.com/articles/s41566-021-00813-y • The role of phonons in ultrafast demagnetization https://www.nature.com/articles/s41586-021-04306-4 • New experimental approaches to two-dimensional electronic spectroscopy https://pubs.aip.org/aip/rsi/article/85/12/123107/109430/
Intended learning outcomes	Students • comprehend an interesting physical topic in a short time frame • identify and interpret the appropriate literature • select and organize the relevant information for the presentation • compose a presentation on the topic at the appropriate level for the audience • give a presentation to a scientific audience and use the appropriate presentation techniques and tools • criticize and defend the topic in a scientific discussion
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	45 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-67112** Advanced microscopic techniques	
Module code	FAU-67112
Module title (German)	Advanced microscopic techniques
Module title (English)	Advanced microscopic techniques
Person responsible for the module	Prof. Dr. Vahid Sandoghdar (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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, ...)	Main seminar: Advanced Microscopic Techniques (2 SWS)
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	In this course we will cover the following topics: • Confocal microscopy: Confocal microscopy is an imaging technique which provides improved resolution and contrast compared to full field imaging by using a pin hole which helps reducing the out of focus light. Confocal microscopes are backbone for most of biological labs and are used frequently to study cellular mechanics. • Optical coherence tomography imaging (OCT): OCT is an imaging technique which can provide axial resolution better than 1 micron using broadband low coherence light source. This has allowed to perform optical biopsies for several biological samples in vivo. • Raman microscopy : Raman microscopy is a technique within vibrational spectroscopy, which is based on the inelastic scattering of light. It provides information on the chemical composition of the sample based on its vibrational spectra. Since the development of the first commercial Raman spectrometer in 1953, advances in lasers and detectors and the discovery of new phenomena have expanded the use of this technique in several research fields. • Stochastic optical reconstruction microscopy (STORM): STORM is one of the most ubiquitously employed super-resolution imaging techniques. It utilizes sequential activation and time-resolved localization of photoswitchable fluorophores to create high resolution images. During imaging, only an optically resolvable subset of fluorophores is activated to a fluorescent state at any given moment, such that the position of each individual fluorophore can be determined with high precision. • Stimulated emission depletion (STED): STED creates super-resolution images by the selective deactivation of fluorophores, minimising the area of illumination at the focal point, and thus enhancing the achievable resolution for a given system. • Multi-photon excitation (MPE): MPE microscopy is an imaging technique which operates in nonlinear regime that combines point scanning methods with multiphoton fluorescence to create high-resolution, three-dimensional images of biological samples. Several forms of MPE such as 2 photon, 3 photon microscopy etc, are available. MPE is particularly useful in biology because it can be used to probe delicate living cells and tissues without damaging the sample. • Phase contrast microscopy (PCM): Several cells offer very low contrast when visualized with standard microscope. PCM provides improved contrast and is a label-free imaging technique allowing visualization of transparent cells. The quantitative phase contrast image provides information about the optical path length change introduced by the sample because of its refractive index and thickness. • Polarization sensitive optical coherence tomography (ps-OCT): ps-OCT is gaining attention because of its ability to diagnose certain pathological conditions at an early stage. Several pathological conditions such as cancer can be detected at an early stage by measuring birefringent properties of the tissue. ps-OCT uses low coherence polarized light to probe the birerefregence of the tissue. • Brillouin Microscopy: Brillouin microscopy is an emerging optical technique that enables non- contact measurement of viscoelastic properties of a material with diffraction-limited resolution in 3D

Intended learning outcomes	Students • Explain various microscopy techniques • Study specific examples where the techniques are relevant • Visit the labs at MPL if possible, to see an available technique
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-67127** Nonlinear and Quantum Optics	
Module code	FAU-67127
Module title (German)	Nonlinear and Quantum Optics
Module title (English)	Nonlinear and Quantum Optics
Person responsible for the module	Prof. Dr. Maria Chekhova (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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, ...)	Main Seminar 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	Non-exhaustive list of topics for the seminar: • Two-photon absorption with entangled photons • Fibre sources of nonclassical light • Nanoscale quantum nonlinear optics • Sensing with undetected photons • Nonlinear optics with noble gases • The 'simplest' nonlinear optical system: a single atom • Quantum optics with parabolic mirrors • Machine Learning for Quantum State Estimation • Artificial Intelligence for Designing Quantum Optics Experiments and Photonic Devices

Intended learning outcomes	Students • comprehend an interesting physical topic in a short time frame • identify and interpret the appropriate literature • select and organize the relevant information for the presentation • compose a presentation on the topic at the appropriate level for the audience • use the appropriate presentation techniques and tools • criticize and defend the topic in a scientific discussion
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-67143** Advanced nonlinear optics	
Module code	FAU-67143
Module title (German)	Advanced nonlinear optics
Module title (English)	Advanced nonlinear optics
Person responsible for the module	Prof. Dr. Maria Chekhova (FAU) Dr. Hannieh Fattahi (FAU) Prof. Dr. Nicolas Joly (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	The goal of this lecture is to explore advanced concepts of nonlinear optics and their applications. This will cover the following topics: • Nonlinear propagation in solid-core photonic crystal fibres (modulation instability, four-wave mixing, soliton dynamics, supercontinuum generation) and in hollow-core photonic crystal fibres (generation of tunable dispersive waves, plasma in fibres) • Nonlinear optical effects (parametric down-conversion, four-wave mixing, modulation instability) for the generation of nonclassical light (entangled photons, squeezed light, twin beams, heralded single photons). • Nonlinear effects for generating high energy sub cycle pulses (kerr-lens mode-locking, Yb:YAG laser technology, optical parametric amplification, pulses synthesis, attosecond pulse generation)

Intended learning outcomes	The students • understand nonlinear propagation in solid-core and hollow-core photonic crystal fibers • can analyze key nonlinear effects such as modulation instability, four-wave mixing, and soliton dynamics • are familiar with nonlinear optical processes for generating nonclassical light, including entangled photons and squeezed states • understand techniques for high-energy sub-cycle pulse generation, including Kerr-lens mode-locking and optical parametric amplification • can apply advanced nonlinear concepts to modern laser technologies and ultrafast optics
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	Englisch

Modul **FAU-67145** Waveguides, optical fibres and photonic crystal fibres	
Module code	FAU-67145
Module title (German)	Waveguides, optical fibres and photonic crystal fibres
Module title (English)	Waveguides, optical fibres and photonic crystal fibres
Person responsible for the module	Prof. Dr. Nicolas Joly (FAU) Prof. Dr.-Ing. Bernhard Schmauß (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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 with exercises: Waveguides, optical fibres and photonic crystal fibres (4 SWS)
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	This module covers the fundamental principles and applications of optical waveguides, including conventional optical fibres and photonic crystal fibres. Topics include light propagation in dielectric waveguides, mode theory, dispersion, and nonlinear effects. The course explores different fibre types, such as step-index, graded-index, and hollow-core fibres, along with their fabrication and characterization techniques. Special emphasis is placed on photonic crystal fibres, their unique guiding mechanisms, and their applications in nonlinear optics, sensing, and high-power laser systems.

Intended learning outcomes	The students • understand light propagation in optical waveguides and fibres based on mode theory • can analyze dispersion and nonlinear effects in different fibre types • are familiar with the properties, fabrication, and characterization of optical and photonic crystal fibres can explain the unique guiding mechanisms of photonic crystal fibres and their applications are able to evaluate the use of optical fibres in sensing, communication, and high-power laser systems
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-67156** Quantum Computing

Module code	FAU-67156
Module title (German)	Quantum Computing
Module title (English)	Quantum Computing
Person responsible for the module	Prof. Dr. Michael Hartmann (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	The course provides an introduction to quantum computing. The development of quantum hardware has progressed substantially in recent years and has now reached a level of maturity where first industrial applications are being explored. This course will introduce the fundamental ingredients of quantum algorithms, quantum bits and quantum gates, the most important hardware implementations and in particular algorithms that can run on near term hardware implementations of so called Noisy Intermediate Scale Quantum (NISQ) devices. The course will be completed with introductions to the basic concepts of error correction, which is needed in the next stage of development to fully exploit the potential of this emerging computing technology. Prerequisites: the main concepts of quantum theory, including quantum states, the Schrödinger equation, unitary evolution and measurements.

Intended learning outcomes	The students understand the fundamental principles of quantum computing, including qubits and quantum gates are familiar with key quantum algorithms and their applications on Noisy Intermediate-Scale Quantum (NISQ) devices can analyze different quantum hardware implementations and their challenges understand the basics of quantum error correction and its role in future quantum computing developments can assess the potential and limitations of quantum computing for real-world applications.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	The course will present all the relevant material. Useful additional reading contains • "Quantum Computation and Quantum Information by Nielsen and Chuang (Cambridge Univ. Press), • "Quantum Computating: A Gentle Introduction by Rieffel and Polak (MIT Press) • as well as lecture notes by John Preskill available at https://www.preskill.caltech.edu/ph229/ • and Ronald de Wolf available at https://homepages.cwi.nl/~rdewolf/qc19.html .
Language of instruction	English

Modul **FAU-713618** Computer Vision

Module code	FAU-713618
Module title (German)	Computer Vision
Module title (English)	Computer Vision
Person responsible for the module	Prof. Dr. Bernhard Egger (FAU) Prof. Dr.-Ing. Andreas Maier (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	This lecture discusses important algorithms from the field of computer vision. The emphasis lies on 3-D vision algorithms, covering the geometric foundations of computer vision, and central algorithms such as stereo vision, structure from motion, optical flow, and 3-D multiview reconstruction. Participants of this advanced course are expected to bring experience from prior lectures either from the field of pattern recognition or from the field of computer graphics.

Intended learning outcomes	The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants • describe perspective projection, rotations, and related geometric foundations, • explain the presented methods, • discuss the advantages and disadvantages of different modalities for acquiring 3-D information, • implement individually and in small groups code, • discover best practices in data acquisition, • explore and rank different choices for evaluation, • discuss and present in groups the advantages and disadvantages of their implementations, • discuss and reflect the social impact of applications of computer vision algorithms.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.
Language of instruction	English

Modul **FAU-763337** Laser Tissue Interaction	
Module code	FAU-763337
Module title (German)	Laser Tissue Interaction
Module title (English)	Laser Tissue Interaction
Person responsible for the module	Dr.-Ing. Florian Klämpfl (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	This module explores the fundamental principles of light-tissue interaction, focusing on both theoretical and practical aspects. It begins with an introduction to wave optics and the scattering mechanisms of light in biological tissue. The course covers key laser-tissue interaction processes, including absorption, scattering, and thermal effects, along with methods for modeling light propagation in tissue. Students will learn about the radiative transfer equation (RTE) and Monte Carlo (MC) simulations for photon transport. Techniques for determining the optical properties of tissue and the use of optical phantoms for experimental validation are also discussed. Finally, the module introduces selected diagnostic and therapeutic laser applications in medicine.

Intended learning outcomes	The students can explain • the basic properties of light using waveoptics • scattering mechanisms of light • the mechanisms of laser/tissue interaction • different methods for the modelling of light propagation in tissue • the RTE and apply MC for simulations of photon transport • and apply the basic procedures to determine the optical properties of tissue • the use and production of optical phantoms • selected diagnostic and therapeutic applications of light and lasers
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--
Recommended reading	--
Language of instruction	English

Modul **FAU-901895** Deep Learning	
Module code	FAU-901895
Module title (German)	Deep Learning
Module title (English)	Deep Learning
Person responsible for the module	Felix Denzinger (FAU) Prof. Dr.-Ing. Andreas Maier (FAU) Fabian Wagner (FAU)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 SWS and exercise 2 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h

Content	Deep Learning (DL) has attracted much interest in a wide range of applications such as image recognition, speech recognition and artificial intelligence, both from academia and industry. This lecture introduces the core elements of neural networks and deep learning, it comprises: • (multilayer) perceptron, backpropagation, fully connected neural networks • loss functions and optimization strategies • convolutional neural networks (CNNs) • activation functions • regularization strategies • common practices for training and evaluating neural networks • visualization of networks and results • common architectures, such as LeNet, Alexnet, VGG, GoogleNet • recurrent neural networks (RNN, TBPTT, LSTM, GRU) • deep reinforcement learning • unsupervised learning (autoencoder, RBM, DBM, VAE) • generative adversarial networks (GANs) • weakly supervised learning • applications of deep learning (segmentation, object detection, speech recognition, ...) The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.
Intended learning outcomes	The students • explain the different neural network components, • compare and analyze methods for optimization and regularization of neural networks, • compare and analyze different CNN architectures, • explain deep learning techniques for unsupervised / semi-supervised and weakly supervised learning, • explain deep reinforcement learning, • explain different deep learning applications, • implement the presented methods in Python, • autonomously design deep learning techniques and prototypically implement them, • effectively investigate raw data, intermediate results and results of Deep Learning techniques on a computer, • autonomously supplement the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of deep learning applications.
Prerequisites for admission to the module examination	--
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	--

Recommended reading	• Ian Goodfellow, Yoshua Bengio, Aaron Courville: Deep Learning. MIT Press, 2016. • Christopher Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • Yann LeCun, Yoshua Bengio, Geoffrey Hinton: Deep learning. Nature 521, 436444 (28 May 2015)
Language of instruction	English

Modul **KIT-100386** Electromagnetics and Numerical Calculation of Fields	
Module code	KIT-100386
Module title (German)	Electromagnetics and Numerical Calculation of Fields
Module title (English)	Electromagnetics and Numerical Calculation of Fields
Person responsible for the module	Prof. Dr.-Ing. Thomas Zwick (KIT)
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	None
Prerequisite for what other modules	--
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h

Content	This course first gives a comprehensive recap of Maxwell equations and important equations of electromagnetic field theory. In the second part the most important methods of numerical field calculation are introduced: • Maxwell’s equations, materials equations, boundary conditions, fields in ferroelectric and ferromagnetic materials • electric potentials, electric dipole, Coulomb integral, Laplace and Poisson’s equation, separation of variables in cartesian, cylindrical and spherical coordinates • Dirichlet Problem, Neumann Problem, Greens function, Field energy density and Poynting vector, • electrostatic field energy, coefficients of capacitance, vector potential, Coulomb gauge, Biot-Savart-law, magnetic field energy, coefficients of inductance magnetic flux and coefficients of mutual inductance, field problems in steady electric currents, • law of induction, displacement current general wave equation for E and H, Helmholtz equation • skin effect, penetration depth, eddy currents • retarded potentials, Coulomb integral with retarded potentials • wave equation for potential and Vector potential and A, Lorentz gauge, plane waves • Hertzian dipole, near field solution, far field solution • transmission lines, fields in coaxial transmission lines • waveguides, TM-waves, TE-waves • finite difference method FDM • finite difference - time domain FDTD, Yee ´s algorithm • finite difference - frequency domain • finite integration method FIM • finite element method FEM • boundary element method BEM, Method of Moments (MOM), Transmission Line Matrix Method (TLM), • solving large systems of linear equations • basic rules for good numerical field calculation The lecturer reserves the right to alter the contents of the course without prior notification.

Intended learning outcomes	Students with very different background in electromagnetic field theory will be brought to a high level of comprehension. They will understand the concept of electric & magnetic fields and of electric potential & vector potential and they will be able to solve simple problems of electric & magnetic fields using mathematics. They will understand the equations and solutions of wave creation and wave propagation. Finally the student will have learnt the basics of numerical field calculation and be able to use software packages of numerical field calculation in a comprehensive and critical way. The student will • be able to deal with all quantities of electromagnetic field theory (E, D, B, H, J, M, P, ...), in particular: how to calculate and how to measure them, • derive various equations from the Maxwell equations to solve simple field problems (electrostatics, magnetostatics, steady currents, electromagnetics), • be able to deal with the concept of field energy density and solve practical problems using it (coefficients of capacitance and coefficients of inductance), • be able to derive and use the wave equation, in particular: to solve problems how to create a wave and calculate solutions of wave propagation through various media, • be able to outline the concepts, the main application areas and the limitations of methods of numerical field calculation (FDM, FDTD, FIM, FEM, BEM, MoM, TLM) • be able to use one exemplary software package of numerical field calculation and solve simple practical problems with it.
Requirements for awarding credit points (type of examination)	Success control is carried out in the form of a written test of 120 minutes.
Recommended reading	• Matthew Sadiku (2001), Numerical Techniques in Electromagnetics. • CRC Press, Boca Raton, 0-8493-1395-3 • Allen Taflove and Susan Hagness (2000), Computational electrodynamics: the finite-difference time-domain method. • Artech House, Boston, 1-58053-076-1 • Nathan Ida and Joao Bastos (1997), Electromagnetics and calculation of fields. • Springer Verlag, New York, 0-387-94877-5 • Z. Haznadar and Z. Stih (2000), Electromagnetic Fields, Waves and Numerical Methods. • IOS Press, Ohmsha, 1 58603 064 7 • M.V.K. Chari and S.J. Salon (2000), Numerical Methods in Electromagnetism, Academic Press, 0 12 615760 X
Language of instruction	English

Modul **KIT-100430** Non-linear Optics	
Module code	KIT-100430
Module title (German)	Non-linear Optics
Module title (English)	Non-linear Optics
Person responsible for the module	Prof. Dr.-Ing. Christian Koos (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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, …)	2 SWS exercise 2 SWS lectures
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 60 h 90 h
Content	1) The nonlinear optical susceptibility: Maxwell´s equations and constitutive relations, relation between electric field and polarization, formal definition and properties of the nonlinear optical susceptibility tensor, 2) Wave propagation in nonlinear anisotropic materials 3) Second-order nonlinear effects and devices: Linear electro-optic effect/ Pockels effect, second-harmonic generation, sum- and difference-frequency generation, phase matching, parametric amplification, optical rectification 4) Third-order nonlinear effects and devices: Nonlinear refractive index and Kerr effect, self- and cross-phase modulation, four-wave mixing, self-focussing, third-harmonic generation 5) Nonlinear effects in active optical devices

Intended learning outcomes	The students • understand and can mathematically describe the effect of basic nonlinear- optical phenomena using optical susceptibility tensors, • understand and can mathematically describe wave propagation in nonlinear anisotropic materials, • have an overview and can quantitatively describe common second-order nonlinear effects comprising the electro-optic effect, second-harmonic generation, sum- and difference frequency generation, parametric amplification and optical rectification, • have an overview and can quantitatively describe the Kerr effect and other common third-order nonlinear effects, comprising self- and cross-phase modulation, four-wave mixing, self-focussing, and third-harmonic generation, • have an overview and can describe nonlinear-optical interaction in active devices such as semiconductor optical amplifiers • conceive the basic principles of various phase-matching techniques and can apply them to practical design problems, • conceive the basic principles electro-optic modulators, can apply them to practical design problems, and have an overview on state-of-the art devices, • conceive the basic principles third-order nonlinear signal processing and can apply them to practical design problems.
Requirements for awarding credit points (type of examination)	30 min oral exam
Recommended reading	R. Boyd. Nonlinear Optics. Academic Press, New York, 1992. E.H. Li S. Chiang Y. Guo, C.K. Kao. Nonlinear Photonics. Springer Verlag, 2002 G. Agrawal, Nonlinear Fiber Optics, Academic Press, San Diego, 1995.
Language of instruction	English

Modul **KIT-100435** Laser Physics	
Module code	KIT-100435
Module title (German)	Laser Physics
Module title (English)	Laser Physics
Person responsible for the module	Prof. Dr. Marc Eichhorn (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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, …)	2 SWS lectures, 2 SWS tutorial
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 55 h 95 h

Content	Within the module the physical basics of lasers, the fundamental processes of light amplification and the formalisms necessary to describe lasers and laser resonators are covered. The generation of laser pulses and various laser architectures as well as realisations are presented in detail. The exercises specifically discuss the topics of laser description, theoretical background as well as the realization of different laser designs. The tasks of the exercise will be handed out at the end of each lecture as well as uploaded to the lecture website and are to be solved for the following exercise, in which the solution will be discussed. Contents: 1 Quantum-mechanical fundamentals of lasers 1.1 Einstein relations and Planck ́s law 1.2 Transition probabilities and matrix elements 1.3 Mode structure of space and the origin of spontaneous emission 1.4 Cross sections and broadening of spectral lines 2 The laser principles 2.1 Population in version and feedback 2.2 Spectroscopic laser rate equations 2.3 Potential model of the laser 3 Optical Resonators 3.1 Linear resonators and stability criterion 3.2 Mode structure and intensity distribution 3.3 Line width of the laser emission 4 Generation of short and ultra-short pulses 4.1 Basics of Q-switching 4.2 Basics of mode locking and ultra-short pulses 5 Laser examples and their applications 5.1 Gas lasers: The Helium-Neon-Laser 5.2 Solid-state lasers 5.2.1 The Nd3+-Laser 5.2.2 The Tm3+-Laser 5.2.3 The Ti3+:Al2O3 Laser 5.3 Special realisations of lasers 5.3.1 Thermal lensing and thermal stress 5.3.2 The fiber laser 5.3.3 The thin-dis laser
Intended learning outcomes	The students understand the fundamental relations and basics of a laser. They obtain the knowledge necessary for understanding and designing lasers (laser media, optical resonators, pumping schemes) and understand the basics and schemes for pulse generation in a laser. They have the knowledge needed for a multitude of lasers: gas, solid-state, fiber and disc lasers from the visible up to the mid-Infrared spectrum.
Recommended reading	M. Eichhorn, Laser physics (Springer) M. Eichhorn, Laserphysik (Springer) A. E. Siegman, Lasers (University Science Books) B. E. A. Saleh, M. C. Teich,Fundamentals of Photonics (Wiley-Interscience) F. K. Kneubu#hl, M. W. Sigrist, Laser (Teubner)

Language of instruction	English

Modul **KIT-100436** Optical Transmitters and Receivers	
Module code	KIT-100436
Module title (German)	Optical Transmitters and Receivers
Module title (English)	Optical Transmitters and Receivers
Person responsible for the module	Prof. Dr. Wolfgang Freude (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 45 h 135 h
Content	The course concentrates on basic optical communication concepts and connects them with the properties of physical components. The following topics are discussed: • Advantages and limitations of optical communication systems • Optical transmitters comprising lasers and modulators • Optical receivers comprising direct and heterodyne reception • Characterization of signal quality
Intended learning outcomes	The students • understand the peculiarities of optical communications, and how optical signals are generated, transmitted and received, • know about sampling, quantization and coding, • learn the basics about noise on reception, • understand the properties of a linear and a nonlinear optical fibre channel, • grasp the idea of channel capacity and spectral efficiency, • know about various forms of modulation, • acquire knowledge of optical transmitter elements, • understand the function of optical amplifiers, • have a basic understanding of optical receivers, • know the sensitivity limits of optical systems, and • understand how these limits are measured.
Requirements for awarding credit points (type of examination)	Oral examination (approx. 20 minutes). The individual dates for the oral examination are offered regularly.

Recommended reading	• Detailed textbook-style lecture notes can be downloaded from the IPQ lecture pages. • Grau, G.; Freude, W.: Optische Nachrichtentechnik, 3. Ed. Berlin: Springer-Verlag 1991. In German. Since 1997 out of print. • Electronic version available via w.freude@kit.edu. • Kaminow, I. P.; Li, Tingye; Willner, A. E. (Eds.): Optical Fiber Telecommunications VI A: Components and Subsystems +VI B: • Systems and Networks', 6th Ed. Elsevier (Imprint: Academic Press), Amsterdam 2013
Language of instruction	English

Modul **KIT-100456** Optical Engineering	
Module code	KIT-100456
Module title (German)	Optical Engineering
Module title (English)	Optical Engineering
Person responsible for the module	Prof. Dr. Wilhelm Stork (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h

Content	The course "Optical Engineering" teaches the practical aspects of designing optical components and instruments such as lenses, microscopes, optical sensors and measurement systems, and optical disc systems (e.g. CD, DVD, HVD). The course explains the layout of modern optical systems and gives an overview over available technology, materials, costs, design methods, as well as optical design software. The lectures will be given in the form of presentations and accompanied by individual and group exercises. The topics of the lectures include: • Introduction (Optical Phenomena) • Ray Optics (thin/thick lenses, principal planes, ABCD-matrices, chief rays, examples: Eye, IOL) • Popular Applications (Magnifying glass, microscope, telescope, Time-of-flight) • Wave Optics (Interference, Diffraction, Spectrometers, LDV) • Aberrations I (Coma, defocus, astigmatism, spherical aberration) • Fourier Optics (Periodical patterns, FFT spectrum, airy-patterns) • Aberration II (Seidel and Zernike Aberrations, MTF, PSF, Example: Eye) • Fourier Optics II (Kirchhoff + Fresnel, contrast, example: Hubble-telescope) • Diffractive Optics Applications (Gratings, holography, IOL, CD/DVD/Blu-Ray-Player) • Interference (Coherence, OCT) • Filters and Mirrors (Filters, antireflection, polarization, micro mirrors, DLPs) • Laser and Laser Safety (Laser principle, laser types, laser safety aspects) • Displays (Pico projectors, LCD, LED, OLED, properties of displays)
Intended learning outcomes	The students from different backgrounds refresh and elaborate their knowledge of engineering optics and photonics. They will get to know the basic principles of optical designs. They will connect these principles with real-world applications and learn about their problems and how to solve them. The students will know about the human view ability and the eye system. After the module they will be able to judge the basic qualities of an optical system by its quantitative data. After the course, students will: • understand fundamental optical phenomena and apply it to solve optical engineering problems; • work with the basic tools of optical engineering, i.e. ray-tracing by abcd-matrices; • get a broad knowledge on real-world applications of optical engineering; • learn about the potential of optical design for industrial, medical and day-to-day applications; • know up-to-date optical engineering problems and its solutions.
Requirements for awarding credit points (type of examination)	Achievement will be examined in an oral examination (approx. 20 minutes).
Recommended reading	• E. Hecht: Optics • J.W. Goodmann: Introduction to Fourier optics • K.K. Sharma: Optics - Principles and Applications

Language of instruction	English

Modul **KIT-100506** Optical Waveguides and Fibers	
Module code	KIT-100506
Module title (German)	Optical Waveguides and Fibers
Module title (English)	Optical Waveguides and Fibers
Person responsible for the module	Prof. Dr.-Ing. Christian Koos (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS + Tutorium 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction: Optical communications Fundamentals of wave propagation in optics: Maxwell´s equations in optical media, wave equation and plane waves, material dispersion, Kramers-Kroig relation and Sellmeier equations, Lorentz and Drude model of refractive index, signal propagation in dispersive media. Slab waveguides: Reflection from a plane dielectric boundary, slab waveguide eigenmodes, radiation modes, inter- and intramodal dispersion, metal-dielectric structures and surface plasmon polariton propagation. Planar integrated waveguides: Basic structures of integrated optical waveguides, guided modes of rectangular waveguides (Marcatili method and effective-index method), basics of numerical methods for mode calculations (finite difference- and finite-element methods), waveguide technologies in integrated optics and associated fabrication methods Optical fibers: Optical fiber basics, step-index fibers (hybrid modes and LP-modes), graded-index fibers (infinitely extended parabolic profile), microstructured fibers and photonic-crystal fibers, fiber technologies and fabrication methods, signal propagation in single-mode fibers, fiber attenuation, dispersion and dispersion compensation Waveguide-based devices: Modeling of dielectric waveguide structures using mode expansion and orthogonality relatons, multimode interference couplers and directional couplers, waveguide gratings, material gain and absorption in optical waveguides, bent waveguides

Intended learning outcomes	The students • conceive the basic principles of light-matter-interaction and wave propagation in dielectric media and can explain the origin and the implications of the Lorentz model and of Kramers-Kronig relation, • are able to quantitatively analyze the dispersive properties of optical media using Sellmeier relations and scientific databases, • can explain and mathematically describe the working principle of an optical slab waveguide and the formation of guided modes, • are able to program a mode solver for a slab waveguide in Matlab, • are familiar with the basic principle of surface plasmon polariton propagation, • know basic structures of planar integrated waveguides and are able to model special cases with semi-analytical approximations such as the Marcatili method or the effective-index method, • are familiar with the basic concepts of numerical mode solvers and the associated limitations, • are familiar with state-of-the-art waveguide technologies in integrated optics and the associated fabrication methods, • know basic concepts of of step-index fibers, graded-index fibers and microstructured fibers, • are able to derive and solve basic relations for step-index fibers from Maxwell's equations, • are familiar with the concept of hybrid and linearly polarized fiber modes, • can mathematically describe signal propagation in single-mode fibers design dispersion-compensated transmission links, • conceive the physical origin of fiber attenuation effects, • are familiar with state-of-the-art fiber technologies and the associated fabrication methods, • can derive models for dielectric waveguide structures using the mode expansion method, • conceive the principles of directional couplers, multi-mode interference couplers, and waveguide gratings, • can mathematically describe active waveguides and waveguide bends
Requirements for awarding credit points (type of examination)	Type of Examination: Oral exam Duration of Examination: approx. 20 minutes Modality of Exam: The written exam is offered continuously upon individual appointment.
Recommended reading	• B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics • G.P. Agrawal: Fiber-optic communication systems • C.-L. Chen: Foundations for guided-wave optics • Katsunari Okamoto: Fundamentals of Optical Waveguides • K. Iizuka: Elements of Photonics
Language of instruction	English

Modul **KIT-100509** Optoelectronic Components	
Module code	KIT-100509
Module title (German)	Optoelectronic Components
Module title (English)	Optoelectronic Components
Person responsible for the module	Prof. Dr. Wolfgang Freude (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h
Content	The course concentrates on the most basic optical communication components. Emphasis is on physical understanding, exploiting results from electromagnetic field theory, (light waveguides), solid-state physics (laser diodes, LED, and photodiodes), and communication theory (receivers, noise). The following components are discussed: • Light wave guides: Wave propagation, slab. wave guides, strip wave guides, integrated optical wave guides, fibre waveguides • Light sources and amplifiers: Luminescence and laser radiation, luminescent diodes, laser diodes, stationary and dynamic behavior, semiconductor optical amplifiers • Receivers: pin photo diodes, electronic amplifiers, noise
Intended learning outcomes	Comprehending the physical layer of optical communication systems. Developing a basic understanding which enables a designer to read a device´s data sheet, to make most of its properties, and to avoid hitting its limitations. The students • understand the components of the physical layer of optical communication systems • acquire the knowledge of operation principles and impairments of optical wave guides • know the basics of laser diodes, luminescence diodes and semiconductor optical amplifiers • understand pin-photodiodes • know the systems´ sensitivity limits, which are caused by optical and electrical noise

Requirements for awarding credit points (type of examination)	30 min oral exam
Recommended reading	Detailed textbook-style lecture notes as well as the presentation slides can be downloaded from the IPQ lecture pages. Agrawal, G.P.: Lightwave technology. Hoboken: John Wiley & Sons 2004 Iizuka, K.: Elements of photonics. Vol. I, especially Vol. II. Hoboken: John Wiley & Sons 2002 Further textbooks in German (also in electronic form) can be named on request.
Language of instruction	English

Modul **KIT-100512** Light and Display Engineering

Module code	KIT-100512
Module title (German)	Light and Display Engineering
Module title (English)	Light and Display Engineering
Person responsible for the module	Dr.-Ing. Rainer Kling (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS + Tutorium 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Motivation: Light & Display Engineering Light, the Eye and the Visual System (including Melatonin) Fundamentals in Light Engineering Light in non - visual Processes (UV Processes) Color and Brightness Light Sources (Halogen, Low Pressure and High Pressure Lamps, LED Engines) and electronic Drivers Displays (Active and Passive Displays: AMOLED, E-ink, TFT Display, Plasma Display) Luminaries (Fundamentals, Design Rules, Simulations) Optical Design (Ray tracing, Reflector design, Computed Ray tracing)

Intended learning outcomes	The students will apply their comprehensive knowledge of physics of optical phenomena to applied optical systems in light and display engineering. These applications span from human sensing with the eye to light technologies with lamps, luminaires and further clarified by demonstrations, models and experiments. The students can derive the description of basic of light engineering starting from the eye and the visual system know how to handle basic metrical units and know how to measure them understand the visible sensing in contrast to radiation measurements comprehend the concepts of colour and colour control are familiar with all types of light sources from low pressure lamps to LED modules conceive the operation principle of various types of drivers know how to set up a luminaire and how simulate a reflector they understand how active (Plasma Displays) and passive displays (TFT Display) work and how to operate them have a good visualization of numerous optical design approaches
Requirements for awarding credit points (type of examination)	Type of Examination: Oral exam Duration of Examination: approx. 25 minutes Modality of Exam: The oral exam is flexibly held by student request after the WS.
Recommended reading	• Simons, Lighting Engineering: Applied Calculations, 2001 • Shunsuke Kobayashi: LCD Backlights, 2009 • Winchip, Fundamentals of Lighting, 2nd Edition, 2011 • Malacara, Handbook of Optical Design, 2004
Language of instruction	English

Modul **KIT-100524** Solar Energy

Module code	KIT-100524
Module title (German)	Solar Energy
Module title (English)	Solar Energy
Person responsible for the module	Prof. Dr. Bryce Sydney Richards (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 3 SWS + Exercise class 1 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	• Introduction: The Sun • Semiconductor fundamentals • Solar cell working principle • First Generation solar cells: silicon wafer based • Second Generation solar cells: thin films of amorphous silicon, copper indium gallium diselenide, cadmium telluride, organic photovoltaics and dye sensitized solar cells • Third Generation Photovoltaics: high-efficiency device concepts incl. tandem solar cells • Modules and system integration • Cell and module characterization techniques • Economics, energy pay-back time, environmental impact • Other solar energy harvesting processes, incl. thermal and solar fuels • Excursion

Intended learning outcomes	The students: • understand the basic working principle of pn-junction solar cells, • learn about the different kinds of solar cells (crystalline and amorphous silicon, CIGS, Cadmium telluride, organic, dyesensitized solar cells, etc.), • get an overview over upcoming third-generation photovoltaic concepts, • receive information on photovoltaic modules and module fabrication, • develop an understanding of solar cell integration and feeding the electrical power to the grid, • get insight into solar concentration and tandem solar cells for highly efficient energy conversion, • compare photovoltaic energy harvesting with solar thermal technologies • understand the environmental impact of solar energy technologies. Die Studentinnen und Studenten können in englischer Fachsprache sehr gut kommunizieren.
Requirements for awarding credit points (type of examination)	Type of Examination: written exam Duration of Examination: 120 Minutes Modality of Exam: One written exam at the end of each semester.
Recommended reading	• P. Würfel: Physics of Solar Cells • V. Quaschning: Renewable Energy Systems • C. Honsberg and S. Bowden, PV Education CD-ROM and website, http://www.pveducation.org/pvcdrom
Language of instruction	English

Modul **KIT-100566** Field Propagation and Coherence	
Module code	KIT-100566
Module title (German)	Field Propagation and Coherence
Module title (English)	Field Propagation and Coherence
Person responsible for the module	Prof. Dr. Wolfgang Freude (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS, Exercise class 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The following selection of topics will be presented: Light waves, modes and rays: Longitudinal and transverse modes, sampling theorem, counting and density of modes ("states") Propagation in multimode waveguides. Near-field and far-field. Impulse response and transfer function. Perurations and mode coupling. Multimode interference (MMI) coupler. Modal noise (speckle) Propagation in homogeneous media: Resolution limit. Non-paracial and paracial optics. Gaussian beam. ABCD matrix Coherence of optical fields: Coherence function and power spectrum. Polarisation, eigenstates and principal states. Measurement of coherence with interferometers (Mach-Zehnder, Michelson). Self-heterodyne and self-homodyne setups

Intended learning outcomes	Presenting in a unified approach the common background of various problems and questions arising in general optics and optical comunications The students know the common properties of counting of modes, density of states and the sampling theorem comprehend the relationship between propagation in multimode waveguides, mode coupling, MMI and speckles can analyze propagation in homogeneous media with respect to system theory, antennas, and the resolution limit of optical instruments understand that coherence as a general concept comprises coherence in time, in space and in polarisation comprehend the implication of complete spatial incoherence, and what is the radiation efficiency of a source with a diameter smaller than a wavelength (the mathematical Hertzian dipole, for instance) can assess when can two incandescent bulbs form an interference pattern in time know under which conditions a heterodyne radio receiver, which is based on a non-stationary interference, actually works
Recommended reading	Detailed lecture notes as well as the presentation slides can be downloaded from the IPQ lecture pages. Additional reading: • Born, M.; Wolf, E.: Principles of optics, 6. Aufl. Oxford: Pergamon Press 1980 • Ghatak, A.: Optics, 3. Ed. New Delhi: Tata McGraw Hill 2005 • Hecht, E.: Optics, 2. Ed. Reading: Addison-Wesley 1974 • Hecht, J.: Understanding fiber optics, 4. Ed. Upper Saddle River: Prentice Hall 2002 • Iizuka, K.: Elements of photonics, Vol. I and II. New York: John Wiley & Sons 2002 • Further textbooks in German (also in electronic form) can be named on request
Language of instruction	English

Modul **KIT-100577** Lighting Design - Theory and Applications	
Module code	KIT-100577
Module title (German)	Lighting Design - Theory and Applications
Module title (English)	Lighting Design - Theory and Applications
Person responsible for the module	Dr.-Ing. Rainer Kling (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Seminar 3 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 45 h 45 h
Content	1) Lighting Design - Introduction form all over the world 2) Lighting Fundamentals 3) Lighting Design Theory 4) Energy Savings and Lighting design 5) Lighting Design Tools 6) Computing Standards 7) Lighting Design Applications (Practical Part) 7.1 Interior Lighting 7.2 Exterior lighting 7.3 IlluminationOwn Calculation Examples (Practical Part)Motivation: Light & Display Engineering 8) Own Calculation Examples (Practical Part)Motivation: Light & Display Engineering

Intended learning outcomes	The students will apply a comprehensive knowledge of Lighting Design from theory, standards and applications in Indoor and Outdoor lighting. Examples and own Lighting design examples as projects. So a practical and theoretical background is applied to Lighting Design. From metrics too Light Planning projects in small exercise groups. The subjects taught are further clarified by demonstrations, models and experiments. Attending students get the knowledge to Lighting Design, in a shorter theoretical part and practical lighting design simulations with examples from all over the world. The students can derive the description of basics of Lighting Design know how to handle basic metrical units and know how to measure them understand the Lighting Design metrics to apply on projects have a good visualization of numerous design approaches realize good Lighting Design with codes and standards. can see energy savings levels for Lighting Design comprehend the lighting design by practical self-computing lessons: can realize own indoor Lighting design concepts for different applications like Office, School, Shops, Gyms & Industry can realize own outdoor Lighting Design concepts for Street lighting, Tunnels, Stade and Parkings can use for realization Relux and Dialux light planning software so set up Project Planning for Lighting Design.
Requirements for awarding credit points (type of examination)	Type of Examination: Oral exam Duration of Examination: approx. 25 minutes Modality of Exam: The oral exam is flexibly held by student request after the WS.
Recommended reading	• J. Livingstone: Designing With Light: The Art, Science and Practice of Architectural Lighting Design, 2014 • S. Russel: The Architecture Of Light: Interior Designer and Lighting Designer, 2012 • M. Karlen: Lighting Design Basics, Indoor Lightin, 2004 • R.H. Simons Lighting Engineering, 2001Simons, Lighting Engineering: Applied Calculations, 2001 • R. Winchip, Fundamentals of Lighting, 2nd Edition, 2011
Language of instruction	English

Modul **KIT-101834** Business Innovation in Optics and Photonics	
Module code	KIT-101834
Module title (German)	Business Innovation in Optics and Photonics
Module title (English)	Business Innovation in Optics and Photonics
Person responsible for the module	Prof. Dr. Werner Nahm (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 34 h 86 h
Content	This course is instructed and presented by external innovation specialists of the R&D, business and management departments of the Carl Zeiss AG. Introduction: Examples of existing smart mobile device applications, Brainstorming for ideas Technology Introduction: Mobile device technology, Optic components, Display technology (LCD, OLED), Tracking and Sensor Technologies in smart mobile devices Group Work Technology Group Presentations Technology Business Case Development/ Business Plan: Market segmentation, Market research, Essentials of finance, How to write a business plan? Management of Intellectual Property (IP): Importance of IP Management, Patent research, Patent claims, Licencing, Patent infringement, Patent litigation Project Design: How to run an agile R&D Project?, Traget costing, Networked product development Agile project simulation Group Work Excursion to Carl Zeiss AG in Oberkochen (full day) Presentation of results of the group work to the new business experts committee of the Carl Zeiss AG

Intended learning outcomes	The student has an understanding how innovative concepts for optical and photonics products are transferred into a successful business development. The student knows about and makes first hands on experiences on business development aspects in a technology start up environment. The students acquire specialized knowledge in technologies and applications in the field of smart mobile solutions for optical applications as well as an introduction into the field of patent rights. The students can organize themselves in groups and distribute and execute tasks. Further they gain competences in the fields teamwork, organization and communication. The studetns understand the implications of intellectual property are able to perform data base research know how to develop a business plan get an understanding of how to design a project are able to develop in small groups innovative business cases for a potential future product
Requirements for awarding credit points (type of examination)	Type of Examination: examination of another type Duration of Examination: 4 group presentations à 20 minutes (approx.) Modality of Exam: The exam consists of four group presentations. 2nd day: Technology Presentation. 3rd day: Development plan presentation. 4th day: Business Canvas presentation. Final presentation at Zeiss visit: Business pitch
Language of instruction	English

Modul **KIT-101900** Spectroscopic Methods	
Module code	KIT-101900
Module title (German)	Spectroscopic Methods
Module title (English)	Spectroscopic Methods
Person responsible for the module	Prof. Dr. Manfred Kappes (KIT) apl. Prof. Dr. Andreas-Neil Unterreiner (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h
Content	1) Introduction to electronic spectroscopy (Born Oppenheimer approximation, Franck-Condon factor, relaxation processes) 2) Fluorescence spectroscopy and microscopy (Jablonski diagram, Kasha's rule, Vavilov's rule, kinetic and lifetime onsiderations, Stokes shift, Lippert equation, fluorescence anisotropy; confocal fluorescence microscopy, advanced icroscopic methods, e.g. STED) 3) Well-defined sample techniques: spectroscopy in molecular beams, in ion traps and on surfaces (laser-induced fluorescence, cavity ringdown spectroscopy, matrix-isolation spectroscopy, photoelectron spectroscopy) 4) Introduction to time-dependent phenomenon including time-dependent perturbation theory for selection rules, spectral line shape 5) Generation and characterization of tunable laser pulses with pulse durations well below 1 picosecond 6) Various methods of pump-probe spectroscopy covering the spectral range from the microwave to the X-ray regime

Intended learning outcomes	The students get introduced into various methodologies of molecular spectroscopy in frequency and time domain. Due to different basic knowledge they first get acquainted with the microscopic physical background, but later on with the interpretation of the respective optical spectra and application in various fields. The students enhance their knowledge on spectroscopic equipment and optical components for the respective spectroscopic and/or microscopic technique. The students • know the quantum mechanical basis of molecular rotational, vibrational and electronic spectroscopy • conceive a microscopic understanding of optical excitation/ deexcitation processes in molecules, i.e. light-matter interaction • understand the interplay between spectroscopic method, experimental design and required optical components • are familiar with sample preparation techniques in molecular spectroscopy (supersonic expansion, ion traps, soft-landing on surfaces, matrix-isolation) • learn time scales of various molecular motions (especially rotation and vibration) before and during chemical/biochemical reactions • will get in touch with timescales and frequencies of molecular properties and experience their interconnection are introduced into linear and nonlinear molecular spectroscopy including two-dimensional techniques such as two-dimensional vibrational spectroscopy)
Prerequisites for admission to the module examination	
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	• Demtröder: Laser Spectroscopy, Rullière: Femtosecond Laser Pulses, Atkins: Molecular Quantum • Mechanics, various review articles
Language of instruction	English

Modul **KIT-101901** Advanced Inorganic Materials

Module code	KIT-101901
Module title (German)	Advanced Inorganic Materials
Module title (English)	Advanced Inorganic Materials
Person responsible for the module	Prof. Dr. Claus Feldmann (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 45 h 45 h
Content	Selected aspects of modern functional inorganic materials, including: • High-temperature ceramics and hard materials • Color pigments – from Egyption blue to 2D Bragg stacks • Phosphors, luminescence, spectroscopy • Fast ion conductors and high-power batteries • Superconductors: metals, alloys, oxocuprates and current developments • Porous networks: from zeolites to metalorganic frameworks (MOFs) • Transparent conductive oxides and dye-sensitized solar cells • Magnetic pigments: magnetic recording, superparamagnetism and magnetothermal therapy • Modern thermoelectric materials • Fullerenes and fibre-reinforced composite materials • Nanomaterials: Quantum Dots, hollow spheres and nanotubes . . . and other examples of advanced functional materials

Intended learning outcomes	The students refresh and elaborate their knowledge on inorganic materials, materials chemistry as well as basic inorganic chemistry and solid state chemistry. This comprises fundamental aspects of the chemistry of the elements as well as state-ofthe-art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence) of inorganic functional materials. The students • get familiar with basic inorganic chemistry and solid state chemistry • get familiar with concepts of describing crystal structures • know how to characterize inorganic solid compounds and materials • learn how to prepare inorganic compounds and solid materials • understand general aspects of structure-property relations • comprehend general concepts of solid state chemistry and inorganic functional materials • are able to rationalize fundamental properties of inorganic materials • know general trends in view of a technical application of advanced inorganic materials
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	• A. WEST (current edition): Solid State Chemistry and its Applications, Wiley. • A. GREENWOOD, N. EARNSHAW (current edition), Chemistry of the Elements, Elsevier. • U. MÜLLER (current edition): Inorganic Structural Chemistry, Teubner. • J. E. HUHEEY, E. A. KEITER (current edition): Inorganic Chemistry, Pearson. • Selected reviews (as given in the lecture).
Language of instruction	English

Modul **KIT-101901** Advanced Inorganic Materials	
Module code	KIT-101901
Module title (German)	Advanced Inorganic Materials
Module title (English)	Advanced Inorganic Materials
Person responsible for the module	Prof. Dr. Claus Feldmann (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 45 h 45 h
Content	Selected aspects of modern functional inorganic materials, including: • High-temperature ceramics and hard materials • Color pigments – from Egyption blue to 2D Bragg stacks • Phosphors, luminescence, spectroscopy • Fast ion conductors and high-power batteries • Superconductors: metals, alloys, oxocuprates and current developments • Porous networks: from zeolites to metalorganic frameworks (MOFs) • Transparent conductive oxides and dye-sensitized solar cells • Magnetic pigments: magnetic recording, superparamagnetism and magnetothermal therapy • Modern thermoelectric materials • Fullerenes and fibre-reinforced composite materials • Nanomaterials: Quantum Dots, hollow spheres and nanotubes . . . and other examples of advanced functional materials

Intended learning outcomes	The students refresh and elaborate their knowledge on inorganic materials, materials chemistry as well as basic inorganic chemistry and solid state chemistry. This comprises fundamental aspects of the chemistry of the elements as well as state-ofthe- art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence) of inorganic functional materials. The students • get familiar with basic inorganic chemistry and solid state chemistry • get familiar with concepts of describing crystal structures • know how to characterize inorganic solid compounds and materials • learn how to prepare inorganic compounds and solid materials • understand general aspects of structure-property relations • comprehend general concepts of solid state chemistry and inorganic functional materials • are able to rationalize fundamental properties of inorganic materials • know general trends in view of a technical application of advanced inorganic materials
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	• A. WEST (current edition): Solid State Chemistry and its Applications, Wiley. • A. GREENWOOD, N. EARNSHAW (current edition), Chemistry of the Elements, Elsevier. • U. MÜLLER (current edition): Inorganic Structural Chemistry, Teubner. • J. E. HUHEEY, E. A. KEITER (current edition): Inorganic Chemistry, Pearson. • Selected reviews (as given in the lecture).
Language of instruction	English

Modul **KIT-101905** Imaging Techniques in Light Microscopy	
Module code	KIT-101905
Module title (German)	Imaging Techniques in Light Microscopy
Module title (English)	Imaging Techniques in Light Microscopy
Person responsible for the module	Prof. Dr. Martin Bastmeyer (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h
Content	This lecture series is designed to gain familiarity with fundamentals of biological light microscopy and modern fluorescence techniques. Depending on the content, the students will have lab demonstrations of different microscopes or imaging techniques covered in the lecture. 1) Introduction (History and Basic Principles of Compound Microscopes, Resolution and Contrast, Biological Sample Preparation) 2) Imaging Modes and Contrast Techniques (Biological Amplitude and Phase Objects, Phase Contrast, Interference Contrast, Polarization Microscopy) 3) Fluorescence Microscopy (Microscopic Principles, Fluorescent Dyes and Proteins, Biological Sample Preparation) 4) Laser-Scanning-Microscopy (Basic Principles, Spinning Disk, 2-Photon Microscopy, Optical Sectioning Techniques) 5) Live Cell Imaging (Video Microscopy, Fluorescent Proteins) 6) Special Fluorescence Techniques (FRET, TIRF, FCS) 7) Super Resolution Microscopy (SIM, PALM, dSTORM, STED) 8) Digital images (Image Processing, Data Analysis and Quantification)

Intended learning outcomes	The students • are able to derive the description of geometric- and wave-optical principles of a compound microscope • know the physical principles of fluorescent dyes • understand the configuration of laser scanning microscopes • comprehend digital imaging and image processing • have experienced a hands on laboratory praxis of the different microscopic techniques • understand the biological principles of GFP-expression • know the latest developments in light microscopy • understand how technical development of microscopes has driven basic biological research
Requirements for awarding credit points (type of examination)	Written exam over 120 minutes (depending on the number of participants oral exam over approx.45 min). Modality of Exam: Depending on the number of participants, a written or an oral exam is accomplished. The exact modality of the exam will be announced at the beginning of the semester. The written exam is scheduled for the beginning of the break after the WS. A resit exam is offered at the end of the break.
Recommended reading	Lecture presentations will be accessible in pdf-format Recent review articles will be distributed before the lectures Books: • Alan R. Hibbs: Confocal Microscopy for Biologists, Springer Press • Rafael Yuste (Ed.): Imaging, a laboratory manual, CSH Press • James Pawley: Handbook of biological confocal microscopy, Plenum Press
Language of instruction	English

Modul **KIT-101919** Fabrication and Characterisation of Optoelectronic Devices	
Module code	KIT-101919
Module title (German)	Fabrication and Characterisation of Optoelectronic Devices
Module title (English)	Fabrication and Characterisation of Optoelectronic Devices
Person responsible for the module	Prof. Dr. Bryce Sydney Richards (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h
Content	1) Overview: Opto-electronic Devices 2) Thin-film growth and deposition epitaxial growth of III-V semiconductors, as well as Si and Ge chemical vapour deposition (CVD) based processes, including atomic layer deposition (ALD) physical vapour deposition (PVD) based processes, including evaporation (thermal and e-beam) and sputtering (DC and RF) 3) Lithographic techniques e-beam lithography, optical lithography, laser interference lithography, two-photon lithography, X-ray lithography 4) Etching processes wet- and dry-etching processes for semiconductors, dielectrics and metals 5) Micro-optics micro-optic design in opto-electronic devices 6) Characterissation: materials properties (electron microscopy, crystallinity, bonding energies, elemeental concentrations, layer thicknesses ...) electronic properties (dopant profiling, mobility, minority carrier lifetimes, resistivity, bandgap measurements, ...) optical (spectrophotometry, photoluminescence, ...) electrical (current-voltage measurements, quantum efficiency / spectral response, ...) 7) Excursion (TBA)

Intended learning outcomes	The students build knowledge on process technology for the fabrication of a range of optoelectronic devices, including LEDs, solar cells, laser diodes, photodiodes, etc. They learn to compare the advantages of different technological approaches, including their economic boundary conditions. This is a technologiccal-based course where students will use their prior fundamental knowledge to gain a firm grasp on the fabrication sequences and characterisation (optical, electrical, electronic, materials) steps that are required to realise the above devices. While fulfilling the learning targets, the students possess the basic knowledge about the working principles of optoelectronic devices; comprehend the boundary conditions for the design of optoelectronic devices and have a good understanding of the challenges in microfabrication are familiar with different lithographic techniques, including e-beam lithography, optical lithography, multiple-photon lithography, X-ray lithography, etc. comprehend the different techniques that are available for thin-film deposition of dielectrics, metals and semiconductors understand what role micro-optics can play in such devices be able to determine the most promising characterisation techniques for evaluating material quality, electronic properties, as well as optical and electrical performance. Exposure to different dry- and wet-etching processes to help realise device structures have an understanding of the economic implications of the chosen technologies and their compatibility with highthroughput production
Requirements for awarding credit points (type of examination)	Type of Examination: written exam Duration of Examination: 120 Minutes Modality of Exam: One written exam offered at the end of each semester.
Language of instruction	English

Modul **KIT-101920** X-Ray Optics

Module code	KIT-101920
Module title (German)	X-Ray Optics
Module title (English)	X-Ray Optics
Person responsible for the module	Dr. Arndt Last (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
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 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h
Content	1) Introduction: Application of X-ray optics 2) X-ray generation 3) Propagation of X-rays in matter 4) X-ray detection 5) Types of X-ray optics: reflecting, refracting, diffracting, absorbing 6) Characteristics of X-ray optics 7) Methods to simulate X-ray optics (ray tracing, wave propagation) 8) Manufacturing of X-ray optics 9) Characterization of X-ray optics
Intended learning outcomes	The students know the importance of X-ray optics in science and material analysis can describe the basic phenomena of X-ray generation, propagation and detection can calculate the optical path X-rays will follow are familiar with different types of X-ray optics can decide what X-ray optical component is suited best for what application comprehend the concepts of refraction, reflection, diffraction and absorption and are aware of their importance in X-ray optics know the differences between ray tracing and wave propagation methods and can assess what method is applicable in what case conceive manufacturing methods of X-ray optics know how to characterize X-ray optical components

Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	A. Erko, M. Idir, Th. Krist and A. G. Michette (editors), Modern Developments in X-Ray and Neutron Optics
Language of instruction	English

Modul **KIT-101921** Measurement and Control Systems	
Module code	KIT-101921
Module title (German)	Measurement and Control Systems
Module title (English)	Measurement and Control Systems
Person responsible for the module	Prof. Dr.-Ing. Christoph Stiller (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 45 h 105 h
Content	1) Dynamic systems 2) Properties of important systems and modeling 3) Transfer characteristics and stability 4) State-space description 5) Controller design 6) Fundamentals of measurement 7) Estimation 8) Sensors 9) Introduction to digital measurement Learning type: Lecture and excercise
Intended learning outcomes	The students • possess knowledge in the theory of linear time-invariant systems in time domain, state space, and frequency domain • can formulate as ystem model for practical devices • can design a controller and assess closed-loop stability of the control loop • understand the basic concept of measurement uncertainty and its propagation • are able to estimate parameters from measurements • understand the process and methodology of control engineering • gather insight on interdisciplinary modelling for control of large and complex systems
Requirements for awarding credit points (type of examination)	Written exam 120 min (100%)

Recommended reading	C. Stiller: Measurement and Control, scriptum R. Dorf and R. Bishop: Modern Control Systems, Addison-Wesley C. Phillips and R. Harbor: Feedback Control Systems, Prentice-Hall
Language of instruction	English

Modul **KIT-101923** Machine Vision	
Module code	KIT-101923
Module title (German)	Machine Vision
Module title (English)	Machine Vision
Person responsible for the module	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 60 h 180 h

Content	The lecture on machine vision covers basic techniques of machine vision. It focuses on the following topics: • image preprocessing • edge and corner detection • curve and parameter fitting • color processing • image segmentation • camera optics • pattern recognition • deep learning **Image preprocessing:** The chapter on image processing discusses techniques and algorithms to filter and enhance the image quality. Starting from an analysis of the typical phenomena of digital camera based image capturing the lecture introduces the Fourier transform and the Shannon-Nyquist sampling theorem. Furthermore, it introduces gray level histogram based techniques including high dynamic range imaging. The disussion of image convolution and typical filters for image enhancement concludes the chapter. **Edge and corner detection:** Gray level edges and gray level corners play an important role in machine vision since gray level edges often reveal valueable information about the boundaries and shape of objects. Gray level corners can be used as feature points since they can be identified easily in other images. This chapter introduces filters and algorithms to reveal gray level edges and gray level corners like the Canny edge detector and the Harris corner detector. **Curve and parameter fitting:** In order to describe an image by means of geometric primitives (e.g. lines, circles, ellipses) instead of just pixels robust curve and parameter fitting algorithms are necessary. The lecture introduces and discusses the Hough transform, total least sum of squares parameter fitting as well as robust alternatives (M-estimators, least trimmed sum of squares, RANSAC) **Color processing:** The short chapter on color processing discusses the role of color information in machine vision and introduces various models for color understanding and color representation. It concludes with the topic of color consistency. **Image Segmentation:** Image segmentation belongs to the core techniques of machine vision. The goal of image segmentation is to subdivide the image into several areas. Each area shares common properties, i.e. similar color, similar hatching, or similar semantic lecture introduces the most important approaches ranging from the simpler algorithms like region growing, connected components labeling, and morphological operations up to highly flexible and powerful methods like level set approaches and random fields. **Camera optics:** The content of an image is related by the optics of the camera to the 3-dimensional world. In this chapter the lecture introduces optical models that describe the relationship between the world and the image including the pinhole camera model, the thin lens model, telecentric cameras, and catadioptric sensors. Furthermore, the lecture introduces camera calibration methods that can be used to determine the optical mapping of a real camera.

Intended learning outcomes	After having participated in th lecture the participants have gained knowledge on modern techniques of machine vision and pattern recognition which can be used to evaluatecamera images. This especially includes techniques in the areas of gray level image analysis, analysis of color images, segementation of images, describing the geometrical relationship between the image and the 3-dimensional world, and pattern recognition with various classification techniques. The participants have learned to analyze the algorithms mathematically, to implement them in software, and to apply them to tasks in video analysis. The participants are able to analyze real-world problems and to develop appropriate solutions.
Requirements for awarding credit points (type of examination)	60 min written exam
Additional information on the module	**Pattern recognition:** Pattern recognition aims at recognizing semantic information in an image, i.e. not just analyzing gray values or colors of pixels but revealing which kind of object is shown by the pixels. This task goes beyond classical measurement theory and enters the large field of artificial intelligence. Rather than just being developed and optimized by a programmer, the algorithms are adapting themselves to their specific task using training algorithms that are based on large collections of sample images. The chapter of pattern recognition introduces standard techniques of pattern recognition in the context of image understanding like the support vector machine (SVM), decision trees, ensemble and boosting techniques. It combines those classifiers with powerful feature representation techniques like the histogram of oriented gradients (HOG) features, locally binary patterns (LBP), and Haar features. **Deep learning:** Throughout recent years standard pattern recognition technqiues have more and more been outperformed by deep learning introduces multi layer perceptrons as the most relevant form of artificial neural networks, discusses training algorithms and strategies to achieve powerful classifiers based on deep learning including deep auto encoders, convolutional networks, and multi task learning, among others.
Recommended reading	Main results are summarized in the slides that are made available as pdf-files. Further recommendations will be presented in the lecture.
Language of instruction	English

Modul **KIT-101924** Solar Thermal Energy Systems	
Module code	KIT-101924
Module title (German)	Solar Thermal Energy Systems
Module title (English)	Solar Thermal Energy Systems
Person responsible for the module	apl. Prof. Dr. Ron Dagan (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture + tutorial 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	1) Introduction to solar energy: Energy resources, consumption and costs 2) The sun as an energy resource: Structure of the sun, Black body radiation, solar constant, solar spectral distribution Sun-Earth geometrical relationship 3) Passive and active solar thermal applications. 4) Fundamentals of thermodynamics and heat transfer 5) Solar thermal systems - solar collector-types, concentrating collectors, solar towers. Heat losses and efficiency 6) Energy storage The course deals with fundamental aspects of solar energy. Starting from a global energy panorama the course deals with the sun as a thermal energy source. In this context, basic issues such as the sun's structure, blackbody radiation and solar–earth geometrical relationship are discussed. In the next part, the lectures cover passive and active thermal applications and review various solar collector types including concentrating collectors and solar towers and the concept of solar tracking. Further, the collector design parameters determination is elaborated, leading to improved efficiency. This topic is augmented by a review of the main laws of thermodynamics and relevant heat transfer mechanisms. The course ends with an overview on energy storage concepts which enhance practically the benefits of solar thermal energy systems.

Intended learning outcomes	The students get familiar with the global energy demand and the role of renewable energies learn about improved designs for using efficiently the potential of solar energy gain basic understanding of the main thermal hydraulic phenomena which support the work on future innovative applications will be able to evaluate quantitatively various aspects of the thermal solar systems
Requirements for awarding credit points (type of examination)	oral exam of about 30 minutes
Recommended reading	• Foster, Ghassemi, cota,; Solar Energy • Duffie and Beckman; Solar engineering of thermal processes • Holman:, Heat transfer • Heinzel; script to solar thermal energy (in German)
Language of instruction	English

Modul **KIT-101931** Modern Physics	
Module code	KIT-101931
Module title (German)	Modern Physics
Module title (English)	Modern Physics
Person responsible for the module	apl. Prof. Dr. Bernd Pilawa (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 45 h 105 h
Content	1) Introduction 2) Electromagnetism 3) Special Relativity 4) Quantum mechanics 5) Atoms 6) Solids

Intended learning outcomes	The students from different backgrounds refresh and elaborate their knowledge of basic physics. They comprehend the fundamentals of quantum physics and their application to atoms, nuclei and particles. They learn how to describe physical laws in a mathematical form and how to solve problems in modern physics by mathematical evaluation of these physical laws. Learning targets The students • are familiar with the basic experimental results leading to Maxwell's equations • know how to apply Maxwell’s equations to simple problems in electromagnetism • conceive the relation between relativity and electromagnetism • comprehend the coherence of the particle and wave description of light and matter • understand the basic principles leading to the Schrödinger-equation • are able to apply the Schrödinger-equation to basic problems in quantum mechanics • comprehend the limits of wave mechanics • have a good understanding of atoms with many electrons • know the fundamental properties of solids and especially the properties of electrons in crystalline solids.
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	Paul A. Tipler: Physics for engineers and scientists Paul A. Tipler: Modern Physics
Language of instruction	Englisch

Modul **KIT-102054** Condensed Matter Theory I, Fundamentals	
Module code	KIT-102054
Module title (German)	Condensed Matter Theory I, Fundamentals
Module title (English)	Condensed Matter Theory I, Fundamentals
Person responsible for the module	Prof. Dr. Markus Garst (KIT) Prof. Dr. Alexander Mirlin (KIT) Prof. Dr. Alexander Shnirman (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h
Content	Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are: • Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons; • Electronic transport properties of solids, Boltzmann equation; • Solids in an external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect; • Electron-electron interaction, Stoner theory of ferromagnetism; • Landau theory of Fermi liquids; Phonons and electron-phonon interaction
Intended learning outcomes	Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a limited class of problems in the field of condensed matter physics.
Requirements for awarding credit points (type of examination)	Oral Exam. The total duration of the oral exam is approx. 60 minutes.

Recommended reading	• C. Kittel, Einführung in die Festkörperphysik (Oldenburg, 1980) / Introduction to Solid State Physics. • C. Kittel, Quantum Theory of Solids. • N.W. Ashcroft and N.D. Mermin, Solid State Physics (Holt, Rinehart & Winston, N.Y 1976). • J.H. Ziman, Principles of the Theory of Solids (Cambridge, Univ. Press, 1972). • A. A. Abrikosov, Fundamentals of the Theory of Metals
Language of instruction	English

Modul **KIT-102146** Nano-Optics	
Module code	KIT-102146
Module title (German)	Nano-Optics
Module title (English)	Nano-Optics
Person responsible for the module	Dr. Andreas Naber (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h
Content	The lecture gives an introduction to theory and instrumentation of advanced methods in optical microscopy. Emphasis is laid on far- and near-field optical techniques with an optical resolution capability on a 10- to 100-nm-scale which is well below the principal limit of classical microscopy. Applications from different scientific disciplines are discussed (e.g., nano-antennas, single-molecule detection, plasmon-polariton propagation on metal surfaces, imaging of biological cell compartments including membranes).
Intended learning outcomes	The students • improve their understanding of general principles in electrodynamics and optics • have a deeper understanding of the theoretical background in optical imaging and its relation to phenomena on a nanoscale • are familiar with conventional techniques in optical microscopy and make use of their knowledge for the understanding of nano-optical methods • realize the necessity of completely new experimental concepts to overcome the constraints of classical microscopy in the exploration of optical phenomena beyond the diffraction limit • understand the basics of different experimental approaches for optical imaging on a nanoscale • are able to discuss pros and cons of these techniques for applications in different fields of physics and biology • are aware of the importance of nano-optical methods for the elucidation of long-standing interdisciplinary issues

Requirements for awarding credit points (type of examination)	60 min oral exam
Language of instruction	English

Modul **KIT-102280** Theoretical Optics	
Module code	KIT-102280
Module title (German)	Theoretical Optics
Module title (English)	Theoretical Optics
Person responsible for the module	Prof. Dr. Carsten Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	5 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	150 h 50 h 100 h
Content	• Review of Electromagnetism (Maxwell's Equations, Stress Tensor, Material Properties, Kramers-Kronig Relation, Wave Propagation, Poynting's Theorem) • Diffraction Theory (The Principles of Huygens and Fresnel, Scalar Diffraction Theory: Green's Function, Helmholtz- Kirchhoff Theorem, Kirchhoff Formulation of Diffraction, Fresnel-Kirchhoff Diffraction Formula, Rayleigh-Sommerfeld Formulation of Diffraction, Angular Spectrum Method, Fresnel and Fraunhofer Diffraction, Method of Stationary Phases, Basics og Holography) • Crystal Optics (Polarization, Anisotropic Media, Fresnel Equation, Applications) • Classical Coherence Theory (Elementary Coherence Phenomena, Theory of Stochastic Processes, Correlation Functions) • Quantum Optics and Quantum Optical Coherence Theory (Review of Quantum Mechanics, Quantization of the EM Field, Quantum Coherence Functions)

Intended learning outcomes	The students deepen their knowledge about the theory and the mathematical tools in optics and photonics. They learn how to apply these tools to describe fundamental phenomena and how to predict observable quantities that reflect the actual physics from the theory by way of a corresponding purposeful mathematical analyses. They learn how to solve problems of both, interpretative and predictive nature with regards to model systems and real life situations. The students • understand the theoretical basis and physical content of the classical Maxwell equations and the quantum description of light • know how to formulate and discuss optical properties in mathematical form • are able to utilize advanced mathematical tools for the quantitative description of wave propagation in various settings such as anisotropic materials and diffractive systems • are able to quantify and utilize basic phenomena of coherence • are familiar with the quantitative analysis of classical wave propagation in basic devices and systems • appreciate the limitations of the classical description of light and the novel phenomena as sociated with systems for which a quantum description is required • are able to quantitatively analyse simple quantum optical devices
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	• "Classical Electrodynamics" John David Jackson • "Theoretical Optics: An Introduction" Hartmann Römer • "Introduction to Fourier Optics" Joseph W. Goodman • "Introduction to the Theory of Coherence and Polarization of Light" Emil Wolf • "The Quantum Theory of Light " Rodney Loudon
Language of instruction	English

Modul **KIT-102295** Theoretical Nanooptics	
Module code	KIT-102295
Module title (German)	Theoretical Nanooptics
Module title (English)	Theoretical Nanooptics
Person responsible for the module	Prof. Dr. Carsten Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 45 h 135 h
Content	Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections. Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates. Properties of plasmonic nanoparticles and the ability to tune their properties Notion of optical antennas and the discussion of their basic characteristics Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays. Discussion of metamaterials (unit cells, homogenization, light propagation, applications) Transformation optics Analytical modeling and phenomenological tools to describe nanooptical systems

Intended learning outcomes	The students understand dispersion relations for light propagation in various optical systems can describe light interaction with isolated objects and plasmonic nanoparticles are familiar with optical antennas and their fundamental properties can apply coupled mode theory to waveguide arrays understand metamaterials, transformation optics, and analytical modeling techniques for nanooptical systems
Requirements for awarding credit points (type of examination)	Oral Exam. The total duration of the oral exam is approx. 60 minutes
Recommended reading	• L. Novotny and B. Hecht, Principle of Nano-Optics, Cambridge • S. A. Maier, Plasmonics, Springer • J. D. Joannopoulos, S. G. Johnson, J. N. Winn and R. D. Meade, Photonic Crystals: Molding the Flow of Light, University Press
Language of instruction	English

Modul **KIT-102408** Solid-State Optics	
Module code	KIT-102408
Module title (German)	Solid-State Optics
Module title (English)	Solid-State Optics
Person responsible for the module	PD Dr. Michael Hetterich (KIT) Prof. Dr. Heinz Kalt (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
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 SWS + exercise 2 SWS
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h 90 h 210 h
Content	Maxwell's equations, refractive index, dispersion, dielectric function, extinction, absorption, reflection, continuity conditions at interfaces, anisotropic media and layered systems, Drude–Lorentz model, reststrahlen bands, Bloch states and band structure, perturbation theory of light–matter interaction, band to band transitions, joint density of states, van Hove singularities, phonon and exciton polaritons, plasmons, metals, semiconductor heterostructures, low-dimensional systems, group theory and selection rules, nonlinear optics, high-excitation effects in semiconductors, measurement of optical functions: Fourier spectroscopy, ellipsometry, modulation spectroscopy, photoluminescence, reflectometry, absorptivity.

Intended learning outcomes	• know the basic interaction processes between light and matter and are familiar with the polariton concept • can explain the optical properties of insulators, semiconductors (including quantum structures) and metals • comprehend the concept of the dielectric function and can utilize it to calculate relevant optical quantities • are familiar with the classical Drude-Lorentz model and its implications for the optical properties of solids • understand the relation between classical and quantum mechanical models for the dielectric function as well as the importance of the Kramers Kronig relations • can explain near-band-edge optical spectra of semi-conductors and insulators based on the concepts of joint density of states, oscillator strength, as well as excitonic effects • are familiar with common experimental techniques of optical spectroscopy • understand the origin of different optical nonlinearities and high-excitation effects as well as their mathematical description, their experimental realization and their applications • comprehend the basics of group theory and can apply it to solid state optics
Requirements for awarding credit points (type of examination)	60 min oral exam
Recommended reading	• H. Kalt,C.Klingshirn:Semiconductor Optics • F. Wooten:Optical Properties of Solids • P. K. Basu:Theory of optical processes in semiconductors • H. Ibachand, H.Lüth: Solid-State Physics
Language of instruction	English

Modul **KIT-102693** Automotive Vision	
Module code	KIT-102693
Module title (German)	Automotive Vision
Module title (English)	Automotive Vision
Person responsible for the module	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 3 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 45 h 135 h
Content	Machine perception and interpretation of the environment forms the basis for the generation of intelligent behavior. Especially visual perception opens the door to novel automotive applications. Driver assistance systems already improve safety, comfort and efficiency in vehicles. Yet, several decades of research will be required to achieve an automated behavior with a performance equivalent to a human operator. The lecture addresses students in mechanical engineering and related subjects who intend to get an interdisciplinary knowledge in a state-of-the-art technical domain. Machine vision and advanced information processing techniques are presented to provide a broad overview on seeing vehicles. Application examples from cutting-edge and future driver assistance systems illustrate the discussed subjects. The lecture consists out of 2 hours/week of lecture and 1 hour/week of computer exercises. In the computer exercises methods introduced in the lecture will be implemented in MATLAB and tested experimentally.

Intended learning outcomes	After having participated in the lecture the participants have gained knowledge on modern techniques of signal processing and artificial intelligence which can be used to evaluate video sequences, to relate the image content to a spatial context and to interpret the content movements in video sequences, state space modeling and Bayesian filters, and the recognition of road surfaces and object behavior. The participants have learned to analyze the algorithms mathematically, to implement them in software, and to apply them to tasks in autonomous driving and mobile robots. The participants are able to analyze problems in the areas mentioned before and to develop appropriate solutions.
Requirements for awarding credit points (type of examination)	60 min written exam
Recommended reading	TBA
Language of instruction	English

Modul **KIT-103089** Computational Photonics, without ext. Exercises	
Module code	KIT-103089
Module title (German)	Computational Photonics, without ext. Exercises
Module title (English)	Computational Photonics, without ext. Exercises
Person responsible for the module	Prof. Dr. Carsten Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	Transfer Matrix Method to describe the optical response from stratified media Finite Differences to characterize eigenmode in fiber waveguides Beam propagation method to describe the evolution of light in the realm of integrated optics Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D Mie Theory to describe the scattering of light from individual cylindrical or spherical objects Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape Greens’ Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface

Intended learning outcomes	The students can use a computer to solve optical problems and can use a computer to visualize details of the light matter interaction, know different strategies to solve Maxwell's equations on rigorous grounds, know how spatial symmetries and the arrangement of matter in space can be used to formulate Maxwell's equations such that they are amenable for a numerical solution, can implement programs with a reasonable complexity by themselves, can use a computer to discuss and explore optical phenomena, and are familiar with basic computational strategies that emerge in photonics, but comparably in any other scientific discipline as well.
Requirements for awarding credit points (type of examination)	Oral Exam. The total duration of the oral exam is approx. 60 minutes.
Recommended reading	• "Classical Electrodynamics" John David Jackson • "Theoretical Optics: An Introduction" Hartmann Römer • ”Principles of Optics” M. Born and E. Wolf • ”Computational Electro-magnetics: The Finite- Difference Time Domain Method,” A. Taflov and S. C. Hagness • ”Light Scattering by Small Particles” H. C. van de Hulst
Language of instruction	English

Modul **KIT-103093** Quantum Optics	
Module code	KIT-103093
Module title (German)	Quantum Optics
Module title (English)	Quantum Optics
Person responsible for the module	Prof. Dr. Carsten Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS + Exercise class 2 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 90 h 90 h
Content	• Quantization of the electromagnetic field • Various quantum states of light fields: optical photon-number, coherent, squeezed, Schrödinger's cat states • Classical and quantum coherence theory: photon bunching and antibunching • Quantum description of optical interferometry: Mach-Zehnder interferometer with photons • General description of open quantum system: master equation, Heisenberg-Langevin, and stochastic approaches • Optical test of quantum mechanics: Hong-Ou-Mandel, quantum eraser, and Bell's theorem experiments • Interaction of a single atom with a classical field and quantum field • From Rabi model to Jaynes-Cummings model: the most simplest model to describe the light-matter interaction • Quantum master equation approach: description of finite life time of atoms • Weak and strong couplings (spontaneous emission, Purcell effect, resonance fluorescence, lasers, and Rabi oscillation) • Interaction of an ensemble of atoms with a quantum field (Dicke and Tavis-Cummings models, and superradiance) • Quantum optical applications (quantum cryptography, quantum teleportation, quantum metrology, etc.)

Intended learning outcomes	The students of quantum optics comprehend the physics of quantum optical phenomena, the necessary theoretical means for their description, and the application of quantum optical resources in different applications and technologies. They learn how to express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum optical phenomena in specific situations. They are trained to solve basic problems in quantum optics. The students • learn about the quantisation of electromagnetic fields, • understands the details of different quantum states of light, • get an overview over experiments that were important in the development of quantum optics, • develop an understanding for the quantum optical description of the first and second order coherence functions, and • understand and can routinely apply different means to describe the interaction of quantum states of light with quantum emitters.
Requirements for awarding credit points (type of examination)	90 min written exam
Recommended reading	• C. Gerry and P. Knight, Introductory Quantum Optics. • M. O. Scully and M. S. Zubairy, Quantum Optics. • M. Fox, Quantum Optics: An Introduction. • R. Loudon, The Quantum Theory of Light. • D.F. Walls and G. J. Milburn, Quantum Optics. • P. Meystre and M. Sargent, Elements of Quantum Optics. • W. Schleich, Quantum Optics in Phase Space.
Language of instruction	English

Modul **KIT-103252** Optical Systems in Medicine and Life Science	
Module code	KIT-103252
Module title (German)	Optical Systems in Medicine and Life Science
Module title (English)	Optical Systems in Medicine and Life Science
Person responsible for the module	Prof. Dr. Werner Nahm (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h
Content	Optical Systems: Surgical microscope Scanning laser ophthalmoscope (SLO) / Confocal endomicroscope (CEM) Optical coherence tomography (OCT) / Optical biometer Refractive surgical laser Flow-Cytometry Applied Optical Technologies: Magnification and illumination Fluorescence and diffuse reflectance imaging Confocal laser microscopy Low coherence interferometry fs-Laser Laser scattering (Mie-Therory) Systems Design and Engineering: System architecture V-Model of Product Development Process

Intended learning outcomes	**Overall Course Objectives:** This course will allow the students to understand how the basic optical and optoelectronic principles are applied in the design of modern medical devices and routine diagnostic equipment. Besides extending and deepening their expert knowledge in engineering sciences and physics this course will provide profound insight into the applicative, the regulatory and safety and the cost requirements. This will help to be able to understand how the systems are designed to fulfill the requirements. Furthermore, in this course the students will be introduced into case-based learning. The in-class journal club helps to make the students become more familiar with the advanced literature in the field of study. This interactive format helps to improve the students' skills of understanding and debating current topics of active interest. **Teaching Targets:** The successful participation in this course enables the students to derive and formulate system requirements layout the system architecture of optical devices explain the underlying physical and physiological principles and mechanisms elaborate technical and methodological constraints and limitations present, challenge and debate recent research results
Requirements for awarding credit points (type of examination)	60 min written exam
Recommended reading	M. Kaschke, Optical Devices in Opthalmology and Optometry, Willey-VCH
Language of instruction	English

Modul **KIT-103270** Optical Networks and Systems	
Module code	KIT-103270
Module title (German)	Optical Networks and Systems
Module title (English)	Optical Networks and Systems
Person responsible for the module	Prof. Dr.-Ing. Sebastian Randel (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS + Exercise class 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Photonic interconnects: rack-to-rack, board-to-board, chip-to-chip, datacenter interconnects, intensity modulation, direct detection, single-mode fiber vs. multi-mode fiber, serial vs. parallel optics, space-division multiplexing vs. wavelength-division multiplexing, Ethernet (10G, 40G, 100G), Fibre Channel, scaling and energy efficiency. Access neetworks: fiber-to-the-X, passive optical networks (GPON, EPON, NG-PON2, WDM PON), statistical multiplexing vs. point-to-point Metro- and long-haul networks: System-design aspects: dense WDM (ITU grid), optical amplifiers, chromatic dispersion, coherent detection, optical vs. electronic impairment mitigation, capacity limits. Wavelength switching: wavelength selective switch (WSS), reconfigurable optical add-drop multiplexer (ROADM). Standards and protocols: synchronous optical networking and synchronous digital hierarchy (SONET/SDH), optical transport network (OTN), generalized multi-protocol label switching (GMPLS), software-defined networking (SDN). Optical networks in automotive and industrial automotion: polymer-optical fiber (POF), MOST Bus, Profibus and Profinet, optical vs. electrical communication links, overcoming bandwidth limitations using digital signal processing.

Intended learning outcomes	The module provides knowledge about optical networks and systems with applications ranging from photonic interconnects, to fiber-to-the-home (FTTH), optical metro and long-haul networks, and automotive and industrial automation. The role of various network layers will be discussed in conjunction with relevant standards and protocols. Physical-layer specifications of relevant photonic components and system design trade-offs will be introduced. The students get familiar with optical network architectures and protocols learn how to design optical communication systems in a variety of application scenarios understand how application constraints (performance, cost, energy-efficiency) drive technology innovation comprehend the benefits and challenges of using optical communication compared to alternatives (e.g. electrical, and wireless) are familiar with relevant standardization bodies and are able to interpret essential aspects of standard documents.
Requirements for awarding credit points (type of examination)	Type of Examination: oral exam Duration of Examination: 20 min (approx.) Modality of Exam: Oral exams (approx. 20 minutes) are offered throughout the year upon individual appointment.
Recommended reading	Ivan Kaminow, Tingye Li, Alan E. Willner (Editors), Optical Fiber Telecommunications (Sixth Edition), Elsevier Rajiv Ramaswami, Kumar N. Sivarajan and Galen H. Sasaki, Optical Networks (Third Edition), Elsevier
Language of instruction	English

Modul **KIT-103450** Digital Signal Processing in Optical Communications - with Practical Exercises	
Module code	KIT-103450
Module title (German)	Digital Signal Processing in Optical Communications - with Practical Exercises
Module title (English)	Digital Signal Processing in Optical Communications - with Practical Exercises
Person responsible for the module	Prof. Dr.-Ing. Sebastian Randel (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS, Exercise class 2 SWS
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 60 h 120 h
Content	The module deals with algorithms from digital signal processing that are used in broadband optical communication systems. Practical exercises in which the students implement algorithms independently form an essential part of the module. In lectures there will be an introduction to the development of digital coherent transmitters and receivers. Building on this, essential function blocks such as the dispersion compensation, the adaptive equalization of polarization mode dispersion as well as carrier and clock recovery are discussed. In the exercises, these function blocks are to be implemented in software (Matlab, Octave). In addition, individual examples show how digital signal processing algorithms are described in hardware (Hardware Description Language - HDL) and how their complexity scales.

Intended learning outcomes	The students understand the functioning of modern optical communication systems, which combine electro-optical technologies with digital signal processing. You are able to independently implement and test algorithms from digital signal processing as well as suitable simulation and test environments in a suitable scripting language (e.g. Matlab or. Python). Furthermore, they can estimate the influence of interfering effects occurring in the glass fiber such as chromatic dispersion and polarization mode dispersion. You are also able to estimate the complexity and power consumption of the resulting logic circuits.
Requirements for awarding credit points (type of examination)	The exercise sheets and the oral questionnaire are used to rate other types of examinations. The overall impression is assessed. Duration about 20 minutes.
Language of instruction	English

Modul **KIT-103802** Adaptive Optics	
Module code	KIT-103802
Module title (German)	Adaptive Optics
Module title (English)	Adaptive Optics
Person responsible for the module	Prof. Dr. Ulrich Lemmer (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS
ECTS credits	3 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	90 h 30 h 60 h

Content	Adaptive optics is a technology of correcting the effect of atmospheric turbulence on images of space objects and on laser beams propagating through random and highly aberrated media such as turbulence, tissue, and the inside of the human eye, to name just a few applications. The course will familiarize the students with theoretical basics of light propagation through random media, principles of wavefront sensing and reconstruction, as well as wavefront correction with deformable mirrors. The students will also receive solid introduction to statistical optics, the Kolmogorov theory of turbulence, practical aspects of turbulence simulation and modelling of adaptive optics. Theory of turbulence (covariances, structure functions, power spectra, inertial range, dimensional argument of Kolmogorov) Fourier optics (point-spread function, modulation transfer function) Statistical optics (characteristic function, probability density function) Sources and description of aberrations (Zernike polynomials, orthogonality, Marechal criterion) Adaptive optics systems (open- and closed-loop systems, error budgets, tip-tilt correction) Wavefront sensing (Shack-Hartmann wavefront sensor, wavefront reconstruction, wavefront-sensorless AO) Wavefront correction (tip-tilt mirrors, deformable mirrors, piezoelectric effect, microelectromechanical systems, electrostatic actuation) Simulation of adaptive optical systems (analytic vs. end-to-end modelling) Propagation of laser beams through atmospheric turbulence (Gaussian beams, Rytov theory, scintillation index, beam wander) Modelling of free-space optical communication systems (aperture averaging, mean signal-to-noise ratio, false-alarm rate and fade probability, bit error-rate)
Intended learning outcomes	The students will: get familiar with Fourier description of imaging through aberrated optical systems and random media, understand the description of aberrations through Zernike modes, learn how to analytically compute the effects of turbulence on various optical observables such as image/beam motion, temporal power spectra, Zernike modes, scintillation, etc., understand the effect of noise on various quantities and metrics pertinent to the design of adaptive optical systems, understand the advantages and disadvantages of various schemes for wavefront sensing and correction, learn how to simulate and design simple adaptive optics systems.
Requirements for awarding credit points (type of examination)	Type of Examination: Oral examination Duration of Examination: approx. 30 Minutes Modality of Exam: The oral exam will be scheduled during the semester break.
Recommended reading	• Robert K. Tyson, Principles of Adaptive Optics, CRC Press • Michael C. Roggemann, Byron M. Welsh, Imaging through Turbulence, CRC Press

Language of instruction	English

Modul **KIT-105914** Photonic Integrated Circuit Design and Applications	
Module code	KIT-105914
Module title (German)	Photonic Integrated Circuit Design and Applications
Module title (English)	Photonic Integrated Circuit Design and Applications
Person responsible for the module	Prof. Dr.-Ing. Christian Koos (KIT) Prof. Dr.-Ing. Sebastian Randel (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture inclusive Exercise class 2 SWS In addition to the teaching of fundamental concepts to the extent necessary to enable students to perform practical designs, the lecture will focus from the start on a specific technology platform (silicon-on-insulator) in which the students will solve design problems of increasing complexity with the design suite Lumerical. As the final hands-on problem, students will design an entire photonic subsystem for an application of their choice, leaving free room for creative thinking and self-driven work. Since each group of students will present one of the solved designed problems to their peers, students will get exposed to solutions found for and practical problems encountered in a variety of design tasks, providing them with a wider experience base to draw on for future design. Since the class will be taught by lecturers from several Universities, all lectures will be streamed live (with the possibility to interact and to ask questions) and made available online. Design tasks will be performed with the Design Suite Lumerical, for which introductory videos will be made available. An online forum will be provided to allow students to ask questions offline to the lecturers as well as to interact with each other, inside and across Universities.
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h 30 h 150 h

Content	Lectures: Lecture 1: Introduction to silicon photonics Lecture 2: Silicon photonics – technology overview Lecture 3: Wave propagation in silicon photonic waveguides Lecture 4: Mode expansion and orthogonality Lecture 5: Coupled-mode theory Lecture 6: Selected passive devices Lecture 7: Modulators Lecture 8: Photodetectors Lecture 9: Optical amplifiers and lasers Lecture 10: Test and packaging Lecture 11: Optical communications Lecture 12: Optical metrology Lecture 13: Biophotonics and neurophotonics Lecture 14: Integrated quantum optics and optical computing Design lab: Problem Set 1: Mode fields and mode expansion Problem Set 2: Coupling efficiency and coupled-mode theory Design Project A: Optical filter Design Project B: Optical transceiver Design Project C: Optical communication link
Intended learning outcomes	The students understand the basic principles of photonic component design and can apply them to concrete design tasks of increasing complexity and independence, that they will solve in small groups and present to their peers. Doing so they will learn to translate theoretical knowledge gained during the lecture into actionable knowledge used to solve hands-on design tasks. In addition to design principles, students will learn how to satisfy key requirements for making photonic integrated circuits manufacturable and useable in a system environment, such as corner analysis of manufacturing tolerances, design for testability, design for manufacturability, and packaging. In short, we aim at teaching students the skills for hands-on design of manufacturable and application relevant photonic integrated circuits, preparing them to productively contribute to a design team. In addition, we will convey the most recent trends in the application of photonic integrated circuits and let students design a circuit addressing one of these application spaces, giving them a feeling for both the potential as well as the limitations of the technology, so that they may take informed decisions on what systems to integrate in the future.

Requirements for awarding credit points (type of examination)	Part 1 – Solutions of problem sets: We will grade your solutions of the various problem sets and design projects. To this end, please upload your solution via the online teaching platform of your respective institution (see above) before the respective deadline. Please merge all pages into a single pdf file, and please use a scanner. Smartphone made snapshots are often illegible, and in this case your solutions cannot not be evaluated. In case there are any technical difficulties with the platforms, you may also submit your solutions by e–mail to picda@ipq.kit.edu before the respective deadline. Part 2 - Presentation of one pre-assigned problem set: At the beginning of the term, design projects will be pre-assigned to groups of participants. Each of these groups will explain their approach and results to lecturers and peer students in a short presentation (approx. 15 min), followed by approx. 10 min of public discussion with peer students and professors, and an individual private interview of each group member (approx. 10 min per person). The overall impression is rated.
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 (FSU), Dr. O. Stenzel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment 628 M.Sc. Photonics: Compulsory Module 528 M.Sc. Quantum Science and Technology, required elective module, subject area ”specialization”
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	• 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 students • understand the classical interaction of light with matter and basic quantum mechanics • can apply Einstein coefficients, Planck's formula, and selection rules • have a solid understanding of the hydrogen and helium atoms • can analyze molecular spectroscopy data and optical properties of materials • understand the dielectric function, Kramers-Kronig relations, and basic nonlinear optical effects
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	
Recommended reading	Demtröder, ”Experimental physics II” Demtröder, ”Experimental physics III – atoms, molecules and solids” R. Feynman, ”Feynman lectures on physics III quantum mechanics” Jackson, ”Classical ElectrodynamicsE. 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 (FSU), Prof. Dr. S. Nolte (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective Module 628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS and exercise 2 SWS
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	• 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	The students understand the fundamental equations and concepts of laser theory can explain the working principles of different laser types, including gas, ruby, and diode-pumped solid-state lasers are familiar with key laser applications and their underlying physical principles can analyze and compare laser systems in terms of design, performance, and application areas

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	• 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. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 628 M.Sc. Photonics: compulsory module 128 MSc. Physics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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	The students understand the basic principles and wave optical fundamentals of optical metrology are familiar with key sensor technologies and measurement techniques can apply interferometry, holography, and speckle methods for precise measurements understand phase retrieval and its role in optical metrology can analyze and compare metrology techniques for aspheres, freeform surfaces, and confocal methods
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

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

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Specialization in „Optics”. This module is regularly offered in parallel on-site and online (hybrid).
Recommended reading	• 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 **PAFMO122** Biophotonics	
Module code	PAFMO122
Module title (German)	Biophotonics
Module title (English)	Biophotonics
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Prof. Dr. Ralf Ehricht (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 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.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	• 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 **PAFMO129** Computational Imaging	
Module code	PAFMO129
Module title (German)	Computational Imaging
Module title (English)	Computational Imaging
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Dr. Lars Lötgering (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics“: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and Programming Lab 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h

Content	Review: Linear Algebra, Calculus, Python • Optimization part 1: Continuous (Euler Lagrange) and Discrete (multivariate calculus) • Programming lab: genetic algorithms + Fermat principle • Optimization part 2: nonlinear optimization, regularization, Lagrange multipliers • Optimization part 3: Convex techniques, l1 minimization • Programming lab: single pixel camera • Optimization part 4: Automatic differentiation • Matrix representation of coherent optical systems Programming lab: keras toolbox, optical eigenmodes • Multiple scattering: Born / Rytov series, beam propagation method • Tomographic inversion • Programming lab: Foldy-Lax scattering theory • Phase retrieval part 1: coherent diffraction imaging (CDI) • Phase retrieval part 2: ptychography • Programming lab: hybrid input output, shrink wrap, ptychography • Phase retrieval part 3: Fourier ptychography • Image deconvolution: structured illumination microscopy, pupil engineering • Programming lab: extended depth-of-field systems • Imaging with spatially partially coherent light • Parameter estimation: Fisher information and Cramer Rao lower bound • Programming lab: Coded aperture imaging, resolution assessment, edge responses, modulation transfer function, Fourier ring correlation • Neural networks part 1: Image classification • Neural networks part 2: Image regression • Programming lab: digit recognition, counting red blood cells
Intended learning outcomes	Understanding the interplay between forward and inverse modeling in optical systems. Hands-on programming skills.
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Language of instruction	English

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge of a computer programming language and computational physics will be helpful.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to the problem – Maxwell's equations and the wave equation; Free space propagation techniques; Beam propagation methods applied to problems in integrated optics; Mode expansion techniques applied to stratified media; Mode expansion techniques applied to spherical and cylindrical objects; Multiple multipole technique; Boundary integral method; Finite-Difference Time-Domain method; Finite Element Method; Computation of the dispersion relation (band structure) of periodic media; Mode expansion techniques applied to gratings; Other grating techniques; Contemporary problems in computational photonics.
Intended learning outcomes	The course aims at an introduction to various techniques used for computer based optical simulation. Therefore, the student should learn how to solve Maxwell's equations in homogenous and inhomogeneous media rigorously as well as on different levels of approximation. The course concentrates predominantly on teaching numerical techniques that are useful in the field of micro- and nanooptics.

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

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area ”specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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	The students understand light propagation in nonlinear media and the role of the nonlinear susceptibility tensor can describe and analyze parametric effects and second harmonic generation grasp the concept of phase-matching and its importance in nonlinear optical processes are familiar with ultrashort pulse propagation and high-harmonic generation can explain soliton formation and its relevance in nonlinear optics
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”)
Recommended reading	
Language of instruction	English

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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	Students understand the fundamental properties and light propagation in optical fibers are familiar with fiber fabrication, characterization techniques, and special fiber types can analyze fiber-based devices such as amplifiers and lasers understand key applications of optical fibers in communication, sensing, and laser technology

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

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• High-intensity laser technology; • Laser plasma physics; • Laser accelerated particles and applications.
Intended learning outcomes	The students understand the principles of high-intensity laser technology and its key components are familiar with laser-plasma interactions and their physical foundations can analyze laser-driven particle acceleration and its applications in science and technology
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics") If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	• 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 **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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)	90 min written exam
Additional information on the module	
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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	All the image processing and simulations will be practiced in exercises using MatLab and the free image processing toolbox DIPImage (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	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	We will show different methodologies to extract specific information such as for example the average speed of diffusing particles or the locations and areas of cells from the multidimensional image data. Also fitting quantitative models to extracted data will be treated.Simulation of far-field intensity distribution by using simple Fourier-space based approaches is treated with and without considering the vectorial nature of the oscillating electro-magnetic field.

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

Modul **PAFMO183** Introduction to Nanooptics	
Module code	PAFMO183
Module title (German)	Introduction to Nanooptics
Module title (English)	Introduction to Nanooptics
Person responsible for the module	Prof. Dr. I. Staude (FSU), Prof. Dr. T. Pertsch (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area ”specialization
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - 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	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	L. Novotny and B. Hecht, Principles of Nano-Optics, Cambridge 2006; P. Prasad, Nanophotonics, Wiley 2004; J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Photonic Crystals – Molding the Flow of Light, Princeton University Press (2008) list of selected journal publications given during the lecture.
Language of instruction	English

Modul **PAFMO184** Integrated Optics	
Module code	PAFMO184
Module title (German)	Integrated Optics
Module title (English)	Integrated Optics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics": Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, …)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The lecture will cover a significant part of integrated quantum photonics, which is one of the pillars of the current quantum technology development. In particular, the lecture will cover the following topics • Integrated optics on a single photon level • Generation and manipulation of quantum states of light using integrated waveguides • Overview over integrated photonic platforms and fabrication of passive and active waveguide structures • Quantum walks in linear and non-linear waveguide lattices • Introduction to photonic quantum computation and simulation • Measurements using superconducting nanowire single photon detectors and transition edge sensors

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

Modul **PAFMO185** Innovation Methods in Photonics	
Module code	PAFMO185
Module title (German)	Innovation Methods in Photonics
Module title (English)	Innovation Methods in Photonics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics": Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Rapid prototyping technologies in photonics • Innovation management and design thinking • Hands-on/practical examples of photonics prototyping • Entrepreneurial skills and business modelling • Basics of intellectual property rights

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

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	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	The students understand imaging principles, including optical aberrations and coherent imaging can describe key concepts like the amplitude transfer function and 3D pupil function are familiar with holography, optical coherence tomography, and fluorescence microscopy understand light detectors and image sampling requirements can apply computational tools for modeling optical imaging systems
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul **PAFMO220** Micro/Nanotechnology	
Module code	PAFMO220
Module title (German)	Micro/Nanotechnology
Module title (English)	Micro/Nanotechnology
Person responsible for the module	Apl. Prof. Uwe Zeitner (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul **PAFMO221** Microscopy	
Module code	PAFMO221
Module title (German)	Microscopy
Module title (English)	Microscopy
Person responsible for the module	Prof. Dr. R. Heintzmann (FSU), Prof. Dr. C. Eggeling (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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 and enables the students to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
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 (FSU), Dr. F. Setzpfandt (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on quantum theory and theoretical optics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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.

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

Modul **PAFMO261** Quantum Computing	
Module code	PAFMO261
Module title (German)	Quantum Computing
Module title (English)	Quantum Computing
Person responsible for the module	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area ”specialization”
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Basic introduction to algorithms and computing •The Qubit and entanglement thereof • Basics of quantum algorithms • Advanced quantum algorithms • Implementation of QuBits and quantum computers • Hands-on circuits

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

Modul **PAFMO262** Quantum Communicaton	
Module code	PAFMO262
Module title (German)	Quantum Communicaton
Module title (English)	Quantum Communicaton
Person responsible for the module	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. A. Tünnermann (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics": Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in 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 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;
Intended learning outcomes	Goals: The course will give a basic introduction into the usage of quantum states of light for the exchange of generation of quantum light and schemes that leverage these states for the exchange of information, ranging from fundamental concepts and experiments to state of the art implementations for secure communication networks. The course will also give an outlook to aspects of Quantum metrology and imaging.After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.

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.
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul **PAFMO263** Quantum Imaging and Sensing	
Module code	PAFMO263
Module title (German)	Quantum Imaging and Sensing
Module title (English)	Quantum Imaging and Sensing
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. F. Setzpfandt (FSU), Prof. Dr. A. Tünnermann (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics": required elective module 628 M.Sc. Photonics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Basic introduction to relevant concepts of quantumoptics • Generation of photon pairs • Fundamentals of two-photon interference • Applications of two-photon interference • Optical quantum metrology • Ghost Imaging • Quantum microscopy
Intended learning outcomes	Goals: The course will give a basic introduction into the usage of quantum light, in particular photon pairs, for imaging and sensing. To this end, many basic concepts and applications will be introduced and discussed. Furthermore, students will learn how to mathematically describe quantum sensing schemes in order to understand and predict their propreties. After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum imaging and sensing and will be able to apply the derived formalism to similar problems.
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
Additional information on the module	

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

Modul **PAFMO265** Semiconductor Nanomaterials	
Module code	PAFMO265
Module title (German)	Semiconductor Nanomaterials
Module title (English)	Semiconductor Nanomaterials
Person responsible for the module	Prof. Dr. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The course will cover the following topics: • 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.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination at the end of the semester and oral presentation on a current research topic
Additional information on the module	
Recommended reading	P. Y. Yu and M. Cardona, Fundamentals of Semiconductors, Springer 2010 C. F. Klingshirn, Semiconductor Optics, Springer 1995 M. Fox, Quantum Optics – An Introduction, Oxford University Press 2006
Language of instruction	English

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	30 min oral exam

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

Modul **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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100 %). Written examination (100 %). The final grade will be determined by the exercise performance (25%)and an oral exam (75%).
Additional information on the module	

Recommended reading	• 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 (FSU), Dr. O. Stenzel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%).
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	• 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. Gerhard G. Paulus (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	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.
Intended learning outcomes	-
Prerequisites for admission to the module examination	Submission of exercises (type and scope will be announced at the beginning of the semester)

Requirements for awarding credit points (type of examination)	exam (100%) The module grade will consist of graded practice assignments and a written exam or oral presentation.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	• 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 (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in laser physics.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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%).

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	• 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 **PAFMO281** Ultrafast Fibre Laser: Technology and Applications	
Module code	PAFMO281
Module title (German)	Ultrafast Fibre Laser: Technology and Applications
Module title (English)	Ultrafast Fibre Laser: Technology and Applications
Person responsible for the module	Prof. Dr. Markus Schmidt (FSU), Dr. Maria Chernysheva (FSU)
Recommended or expected prior knowledge	Fiber Optics and Ultrafast Optics
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics": required elective module 628 MSc Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 SWS Exercises: 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The course will cover the following topics: • Review of fundamentals of ultrafast fibre lasers (mode-locking and Q-switching • Engineering of fibre laser cavities • Ultrashort pulse characterization (autocorrelatioon, FROG,dispersive Fourier transformation, etc.) • Extreme phenomena, exploration of new wavelength rangesand other latest technology advancements in ultrafast fibrelaser development • Detailed overview of the ultrafast laser applications in industry,sensing, and medicine (diagnostics and treatment)

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

Modul **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 (FSU), Dr. D. Kartashov (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• 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 • XUV- and X-ray microscopy
Intended learning outcomes	The students understand the complex refractive index in the XUV and X-ray range can analyze refractive, grazing incidence, and zone plate optics are familiar with X-ray diffraction and scattering phenomena understand applications in plasma diagnostics and EUV lithography
Prerequisites for admission to the module examination	-

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

Modul **CORE-MT-01** Master thesis	
Module code	CORE-MT-01
Module title (German)	Masterarbeit Photon Science and Technology
Module title (English)	Master thesis
Person responsible for the module	N. Joly (FAU), I. Staude (FSU), C. Rockstuhl (KIT)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: compulsory
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Practical course. total workload: 900 h depending on the topic this total workload should be distributed approximately as: • 225 h introduction to the research topic (study of relevant literature, ...) • 450 h research work (in the lab for experimental topics and at computer etc. for theoretical topics) • 200 h preparation of the final report • 25 h preparation and carrying out presentation of the results
ECTS credits	30 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	900 h 0 h 900 h
Content	The research towards the thesis will be performed in a research group, in an industrial research lab or a research of optics and photonics and will be assigned, supervised, and refereed by a thesis advisory committee. Three educators/representatives from each location form a thesis advisory committee. Committee meetings with the student take place at the beginning of the thesis work and shortly before finalizing of the thesis research work.
Intended learning outcomes	Students learn in-depth scientific working methods. They learn to analyze an elaborate scientific problem, develop suitable solutions, achieve, evaluate and interpret experimental or theoretical results, and summarize and discuss their work in a Ideally, this scientific work is the basis for a continuation of the student's academic progress by transitioning to the MPSP research phase (PhD project).
Prerequisites for admission to the module examination	Students conduct 900 hours of research work including preparation, lab work, thesis writing and presentations.
Requirements for awarding credit points (type of examination)	s. §19 Study Regulations

Additional information on the module	A thesis advisory committee closely supervises the research towards the thesis. In this way, educators from all three teaching universities are involved in the supervision in equal interaction of the student with the committee to emphasize the special importance of the unique cross-locational joint supervision
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
KS/ PR....	Klausur/Prüfung
C....	Colloquium
C/I....	Colloquium/practical work
CS....	Conference/symposium
kV....	Kulturelle Veranstaltung

Abbrevations of lectures

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

Abbrevations of lectures

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

Other 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