

Modulkatalog Master of Science

828 Photon Science and Technology

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FRIEDRICH-SCHILLER-
UNIVERSITÄT
JENA

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Hinweis : Hinweis: Prüfungen, den Prüfungen zugeordnete Lehrveranstaltungen sowie Prüfungstermine können in Friedolin unter dem Menüpunkt "Modulkataloge" eingesehen werden. Nach Login wählen Sie dazu bitte Abschluss, Studiengang und Modul. Unmittelbar eingearbeitete Änderungen werden dort zeitnah dargestellt.

Explanations regarding the module catalogue

Programmüberblick

Der Masterstudiengang Photon Science and Technology ist ein gemeinsamer Studiengang der Friedrich-Schiller-Universität Jena (FSU), der Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) und des Karlsruher Instituts für Technologie (KIT). Es handelt sich um einen in Deutschland einzigartigen, forschungsorientierten Studiengang, der die akademischen Stärken dreier Universitäten aus unterschiedlichen Bundesländern bündelt. Der Studiengang baut auf der langjährigen Zusammenarbeit im Rahmen der Max Planck School of Photonics auf und richtet sich an hochqualifizierte Studierende, die nach dem Bachelorstudium frühzeitig an exzellente Forschung herangeführt werden sollen.

Ziel des Studiengangs ist es, eine exzellente Ausbildung in der Photonik und Optik zu bieten, indem Studierenden das Studium und die Durchführung von Forschungsarbeiten an allen drei Standorten ermöglicht werden. Durch die Bündelung von Expertise, Infrastruktur und Forschungsschwerpunkten erhalten die Studierenden Zugang zu einem breiten und vielfältigen wissenschaftlichen Umfeld.

Studienkonzept und -struktur

Der Studiengang ist forschungsorientiert und fokussiert auf den Erwerb von für wissenschaftliches Arbeiten relevanten Kompetenzen. Lehre und Ausbildung werden gemeinschaftlich von den drei Universitäten organisiert. Zentrale Module werden gemeinsam von Lehrenden aller Standorte durchgeführt, während Laborpraktika und Forschungsphasen eine Mobilität zwischen den Universitäten vorsehen.

Der Studiengang umfasst insgesamt 120 ECTS-Punkte und ist auf vier Semester ausgelegt:

- **Erstes Semester** : Erwerb grundlegender Kenntnisse der Photonenwissenschaft sowie Angleichung unterschiedlicher fachlicher Vorkenntnisse.
- **Zweites und drittes Semester**: Spezialisierung und intensive forschungsbezogene Ausbildung.
- **Viertes Semester**: Anfertigung der Masterarbeit als eigenständige wissenschaftliche Leistung.

Die Lehrformate umfassen gemeinsame Vorlesungen, hybride Lehrveranstaltungen, Laborpraktika und Forschungsprojekte. Die Laborpraktika werden mit rotierender Zuständigkeit der Universitäten organisiert und beinhalten auch innovative Elemente von Remote-Laboren.

Module und Studienverlauf

Im ersten Semester absolvieren die Studierenden kooperative Module wie Introduction to Photon Science, IT and Research Methodology sowie Practical Training. Ein Wahlpflichtbereich Adjustment ermöglicht es den Studierenden, in enger Abstimmung mit dem Koordinationsbüro Lehrveranstaltungen auszuwählen, die an ihren individuellen fachlichen Hintergrund angepasst sind.

Im zweiten und dritten Semester wählen die Studierenden Module aus dem Bereich Fundamental Electives und nehmen am umfassenden, zweisemestrigen Modul Specialization teil. Die Auswahl der Lehrveranstaltungen erfolgt in Abstimmung mit den individuellen Forschungsinteressen. Ein Kolloquium am Ende des dritten Semesters bietet die Möglichkeit, die Inhalte der Spezialisierung mit Studierenden und Lehrenden aller drei Universitäten zu präsentieren und zu diskutieren.

Das Modul Research Training erstreckt sich ebenfalls über das zweite und dritte Semester und umfasst praktische Forschungsarbeiten in zwei unabhängigen Forschungsgruppen an unterschiedlichen Standorten. Das Modul beinhaltet ein benotetes Forschungskolloquium zur Bewertung des Arbeitsfortschritts und zur Unterstützung der Planung der weiteren Forschungsphase.

Der Studiengang schließt im vierten Semester mit der Masterarbeit ab, die vor einem Prüfungsgremium mit Vertreterinnen und Vertretern aller drei Universitäten verteidigt werden muss.

* **Das Modul Specialization besteht aus zwei Teilen** : Im ersten Teil wählen die Studierenden entsprechend ihren individuellen Interessen Lehrveranstaltungen, um vertiefte Kenntnisse in der Photonik zu erwerben. Mögliche Themen sind beispielsweise Biophotonik, Nano- und Mikrooptik, Photonik-Systemdesign, Starkfeldphysik, Röntgenwissenschaften und Quantenoptik. Es müssen Lehrveranstaltungen im Umfang von mindestens 20 ECTS-Punkten erfolgreich absolviert werden. Im zweiten Teil müssen die Studierenden am Ende des dritten Semesters eine Präsentation erfolgreich absolvieren. Diese erfolgt in Form eines Posterpräsentationsseminars im Rahmen der MPSP Spring School und bezieht sich auf den individuellen Spezialisierungspfad und die bearbeiteten Projekte.

Qualifikationsziele

Der Masterstudiengang bereitet die Studierenden auf forschungsorientierte und wissenschaftlich fundierte Tätigkeiten in der Optik und den optischen Technologien sowie auf eine weiterführende akademische Qualifikation vor. Die Absolventinnen und Absolventen erwerben vertiefte Kenntnisse in Optik und Photonik, einschließlich theoretischer Grundlagen, experimenteller Methoden und Anwendungen aus physikalischer und ingenieurwissenschaftlicher Perspektive.

Die Studierenden entwickeln spezialisierte Fachkenntnisse in ausgewählten Schwerpunkten und sammeln Erfahrung in der Durchführung, Dokumentation und Präsentation wissenschaftlicher Arbeiten. Die standortübergreifende Struktur fördert die Entwicklung organisatorischer Fähigkeiten, Selbstständigkeit sowie die Fähigkeit, sich in unterschiedlichen Forschungsumgebungen sicher zu bewegen.

Kompetenzentwicklung

Während des gesamten Studiums erwerben die Studierenden schrittweise Kompetenzen in wissenschaftlicher Methodik, Experimentieren, Datenmanagement, Programmierung und Forschungsethik. Praktische Laborarbeiten, das Research Training sowie die Masterarbeit legen einen besonderen Schwerpunkt auf gute wissenschaftliche Praxis und eigenständige Problemlösung.

Regelmäßige Präsentationen, Kolloquien sowie die Teilnahme an Spring und Autumn Schools stärken die Kommunikationsfähigkeit und den wissenschaftlichen Austausch. Das Studieren und Arbeiten an mehreren Standorten fördert Anpassungsfähigkeit, Selbstorganisation und den Umgang mit unterschiedlichen wissenschaftlichen Kulturen.

Gesamtziel

Zentrales Ziel des Studiengangs ist es, die Studierenden zur selbstständigen wissenschaftlichen Arbeit in der Photonik auf hohem internationalem Niveau zu befähigen. Die strukturierte Abfolge der Module gewährleistet eine kohärente Entwicklung von grundlegenden Kenntnissen hin zu anspruchsvoller Forschung und mündet in der Masterarbeit, in der alle erworbenen Kompetenzen zusammengeführt werden.

Modul CORE-IN-01 Introduction to Photon Science	
Modulcode	CORE-IN-01
Modultitel (deutsch)	Introduction to Photon Science
Modultitel (englisch)	Introduction to Photon Science
Modul-Verantwortliche/r	N. Joly (FAU), I. Staude (FSU), C. Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 4 h per week Exercise: 2 h per week
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	90 h
- Selbststudium	210 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	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

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (60, 90 or 120 mins) Grading: Based on the performance in the written examination.
Zusätzliche Informationen zum Modul	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.
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul CORE-IT-01 Informationstechnische Methoden der modernen Forschung	
Modulcode	CORE-IT-01
Modultitel (deutsch)	Informationstechnische Methoden der modernen Forschung
Modultitel (englisch)	IT and Research Methodology
Modul-Verantwortliche/r	B. Schmauss (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 2 h per week
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>This module conveys competence in using information technology and resources. The course captures the following aspects:</p> <ul style="list-style-type: none"> • 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.
Lern- und Qualifikationsziele	<p>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.</p>

Voraussetzung für die Zulassung zur Modulprüfung	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: written (60, 90, or 120 mins) or oral examination (30, 45, or 60 mins) Grading: from examination result.
Zusätzliche Informationen zum Modul	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.
Empfohlene Literatur	--
Unterrichtssprache	English

Modul CORE-PT-01 Praktische Ausbildung	
Modulcode	CORE-PT-01
Modultitel (deutsch)	Praktische Ausbildung
Modultitel (englisch)	Practical Training
Modul-Verantwortliche/r	S. Nolte (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	6 experimentation sessions with a duration of 5 hours
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	30 h
- Selbststudium	120 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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
Lern- und Qualifikationsziele	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.

Voraussetzung für die Zulassung zur Modulprüfung	<p>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.</p> <p>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.</p> <p>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.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: -</p> <p>Grading: pass / no pass</p>
Zusätzliche Informationen zum Modul	<p>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.</p> <p>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.</p> <p>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.</p>
Unterrichtssprache	Englisch

Modul CORE-RT-01 Research Training	
Modulcode	CORE-RT-01
Modultitel (deutsch)	Research Training
Modultitel (englisch)	Research Training
Modul-Verantwortliche/r	C. Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Practical labwork and seminar.
Leistungspunkte (ECTS credits)	20 LP
Arbeitsaufwand (work load) in:	600 h
- Präsenzstunden	- h
- Selbststudium	- h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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:</p> <ul style="list-style-type: none"> • 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 results <p>After 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.</p> <p>Acquired research skills are presented and relevant skills to acquire with the second project are identified.</p> <p>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.</p>

Inhalte	<p>The student chooses two research projects in two different research groups in the 2nd and 3rd semester.</p> <p>Depending on the topic the total workload of 300h per project should be distributed approximately as:</p> <ul style="list-style-type: none"> • 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 results <p>After 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.</p> <p>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.</p>
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	Written report on first research project and presentation of second research project
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: Seminar presentation of first research project and written report on second presentation</p> <p>Grading: Average of the grades for the presentation and the written report.</p>
Zusätzliche Informationen zum Modul	The students are working on research projects in different labs.
Unterrichtssprache	English

Modul CORE-SP-01 Spezialisierung	
Modulcode	CORE-SP-01
Modultitel (deutsch)	Spezialisierung
Modultitel (englisch)	Specialization
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Leistungspunkte (ECTS credits)	20 LP
Arbeitsaufwand (work load) in:	600 h
- Präsenzstunden	- h
- Selbststudium	- h
(einschl. Prüfungsvorbereitungen)	

Modul FAU-42135 Image Processing in Optical Nanoscopy	
Modulcode	FAU-42135
Modultitel (deutsch)	Image Processing in Optical Nanoscopy
Modultitel (englisch)	Image Processing in Optical Nanoscopy
Modul-Verantwortliche/r	Prof. Dr. Harald Köstler (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	<ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-42140 Optical Lithography: Technology, Physical Effects and Modeling	
Modulcode	FAU-42140
Modultitel (deutsch)	Optical Lithography: Technology, Physical Effects and Modeling
Modultitel (englisch)	Optical Lithography: Technology, Physical Effects and Modeling
Modul-Verantwortliche/r	PD Dr. Andreas Erdmann (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>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 discussed 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.</p>
Lern- und Qualifikationsziele	<p>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.</p>
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.
Unterrichtssprache	Englisch

Modul FAU-42155 Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics	
Modulcode	FAU-42155
Modultitel (deutsch)	Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics
Modultitel (englisch)	Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. Joachim Zanthier (FAU) Prof. Dr. Stephan Götzinger (FAU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	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)
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	90 h
- Selbststudium	210 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>Introduction: Fundamental Properties and working scheme of the Laser, applications</p> <p>Optical resonators: Ray transfer matrix analysis, stability criteria for optical resonators</p> <p>Propagation of waves in optical media: Solutions to the wave equation, complex index of refraction, dispersion</p> <p>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</p> <p>Light-matter interaction: Classical description, semiclassical description, stimulated emission, black body radiation, interaction of a two-level atom with a monochromatic wave</p> <p>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</p> <p>Laser systems: Gas lasers, solid state lasers, vibronic lasers, laser frequency analysis and stabilization</p> <p>Laser spectroscopy: Spectral lines + -profiles, broadening mechanisms, doppler-free spectroscopy</p> <p>Cooling and trapping of atoms: Doppler cooling, magneto-optical trap, trapping of single atoms, Bose-Einstein-condensation</p>
Lern- und Qualifikationsziele	<p>Students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (100%)
Empfohlene Literatur	
Unterrichtssprache	englisch

Modul FAU-42935 Optical diagnostics in energy and process engineering	
Modulcode	FAU-42935
Modultitel (deutsch)	Optical diagnostics in energy and process engineering
Modultitel (englisch)	Optical diagnostics in energy and process engineering
Modul-Verantwortliche/r	Simon Aßmann (FAU) Dr.-Ing. Franz Huber (FAU) Prof. Dr.-Ing. Stefan Will (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>Introduction to conventional and novel optical techniques to measure state and process functions in thermodynamical systems:</p> <ul style="list-style-type: none"> • 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)
Lern- und Qualifikationsziele	<p>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</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	<p>Lecture Slides Bräuer, Andreas: In situ Spectroscopic Techniques at High Pressure, Amsterdam 2015</p>
Unterrichtssprache	Englisch

Modul FAU-43220 Computational Optics	
Modulcode	FAU-43220
Modultitel (deutsch)	Computational Optics
Modultitel (englisch)	Computational Optics
Modul-Verantwortliche/r	Prof. Dr. Christoph Pflaum (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture with exercises: Computational Optics CE & MAOT (2+2 SWS)
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>Students will be able to:</p> <ol style="list-style-type: none"> 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.
Voraussetzung für die Zulassung zur Modulprüfung	--

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-43386 Computational Photography and Capture	
Modulcode	FAU-43386
Modultitel (deutsch)	Computational Photography and Capture
Modultitel (englisch)	Computational Photography and Capture
Modul-Verantwortliche/r	Prof. Dr. Tim Weyrich (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p> <p>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.</p> <p>The lecture covers the following topics:</p> <ul style="list-style-type: none"> • Cameras, sensors and colour • Image processing (e.g., blending, warping) • Radiometry • Appearance acquisition • Structured-light 3D acquisition • Image-based and video-based rendering

Lern- und Qualifikationsziele	The students: <ul style="list-style-type: none">• 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	English

Modul FAU-44120 Pattern Analysis	
Modulcode	FAU-44120
Modultitel (deutsch)	Pattern Analysis
Modultitel (englisch)	Pattern Analysis
Modul-Verantwortliche/r	PD Dr.Ing. Christian Riess (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 3 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods.</p> <p>The topics comprise:</p> <ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	--

Empfohlene Literatur	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
Unterrichtssprache	Englisch

Modul FAU-44141 Medical Image Processing for Interventional Applications	
Modulcode	FAU-44141
Modultitel (deutsch)	Medical Image Processing for Interventional Applications
Modultitel (englisch)	Medical Image Processing for Interventional Applications
Modul-Verantwortliche/r	Prof. Dr.-Ing. Andreas Maier (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p>

Lern- und Qualifikationsziele	<p>The participants:</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-44151 Medical Image Processing for Diagnostic Applications	
Modulcode	FAU-44151
Modultitel (deutsch)	Medical Image Processing for Diagnostic Applications
Modultitel (englisch)	Medical Image Processing for Diagnostic Applications
Modul-Verantwortliche/r	Prof. Dr.-Ing. Andreas Maier (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	<p>The participants</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-45730 Optical Technologies in Life Science	
Modulcode	FAU-45730
Modultitel (deutsch)	Optical Technologies in Life Science
Modultitel (englisch)	Optical Technologies in Life Science
Modul-Verantwortliche/r	PD Dr.habil. Sebastian Schürmann (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture and exercise 4 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>Students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.
Unterrichtssprache	Englisch

Modul FAU-48313 Modern Optics 3: Quantum Optics	
Modulcode	FAU-48313
Modultitel (deutsch)	Modern Optics 3: Quantum Optics
Modultitel (englisch)	Modern Optics 3: Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. Maria Chekhova (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: Modern Optics 3: Quantum Optics (2 SWS)
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Contents:</p> <ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>Learning goals and competences:</p> <p>Students</p> <ul style="list-style-type: none"> • explain the relevant topics of the lecture • apply the methods to specific examples

Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-582360 Modern Optics 2: Nonlinear Optics	
Modulcode	FAU-582360
Modultitel (deutsch)	Modern Optics 2: Nonlinear Optics
Modultitel (englisch)	Modern Optics 2: Nonlinear Optics
Modul-Verantwortliche/r	Prof. Dr. Nicolas Joly (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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.

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	<ul style="list-style-type: none"> • Paul Mandel : Nonlinear Optics (Wiley-VCH 2010) • Robert Boyd: Nonlinear Optics (Academic Press, 2008) • Geoffrey New: Introduction to nonlinear optics (Cambridge University Press, 2011)
Unterrichtssprache	Englisch

Modul FAU-621649 Advanced optical communication systems	
Modulcode	FAU-621649
Modultitel (deutsch)	Advanced optical communication systems
Modultitel (englisch)	Advanced optical communication systems
Modul-Verantwortliche/r	Prof. Dr.-Ing. Bernhard Schmauß (FAU) Lisa-Sophie Härteis (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: Advanced Optical Communication Systems (2 SWS) Exercises: Advanced Optical Communication Systems (2 SWS)
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>Students</p> <ul style="list-style-type: none"> • 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 designs of optical transmission systems. • are able to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.
Unterrichtssprache	Englisch

Modul FAU-66961 Advanced theoretical physics	
Modulcode	FAU-66961
Modultitel (deutsch)	Advanced theoretical physics
Modultitel (englisch)	Advanced theoretical physics
Modul-Verantwortliche/r	Prof. Dr. Kristina Giesel (FAU) Prof. Dr. Hanno Sahlmann (FAU) Prof. Dr. Ana-Suncana Smith (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	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)
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	105 h
- Selbststudium	95 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>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:</p> <ul style="list-style-type: none"> • 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) <p>Course Advanced Solid State Physics (TV-B): The following main topics will be discussed in this course:</p> <ul style="list-style-type: none"> • 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, thermal 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
Lern- und Qualifikationsziele	<p>Course Advanced Quantum Mechanics (TV-A): Students</p> <ul style="list-style-type: none"> • 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 <p>Course Advanced Solid State Physics (TV-B): Students</p> <ul style="list-style-type: none"> • 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

Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (100%)
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-67009 Novel techniques in ultrafast spectroscopy	
Modulcode	FAU-67009
Modultitel (deutsch)	Novel techniques in ultrafast spectroscopy
Modultitel (englisch)	Novel techniques in ultrafast spectroscopy
Modul-Verantwortliche/r	Prof. Dr. Daniele Fausti (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Seminar 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>Review of recently developed techniques for the characterization of the dynamical response of complex materials:</p> <ul style="list-style-type: none"> • 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/
Lern- und Qualifikationsziele	<p>Students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	45 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-67112 Advanced microscopic techniques	
Modulcode	FAU-67112
Modultitel (deutsch)	Advanced microscopic techniques
Modultitel (englisch)	Advanced microscopic techniques
Modul-Verantwortliche/r	Prof. Dr. Vahid Sandoghdar (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Main seminar: Advanced Microscopic Techniques (2 SWS)
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte

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 birefringence 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

Lern- und Qualifikationsziele	Students <ul style="list-style-type: none">• Explain various microscopy techniques• Study specific examples where the techniques are relevant• Visit the labs at MPL if possible, to see an available technique
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-67127 Nonlinear and Quantum Optics	
Modulcode	FAU-67127
Modultitel (deutsch)	Nonlinear and Quantum Optics
Modultitel (englisch)	Nonlinear and Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. Maria Chekhova (FAU)
Voraussetzung für die Zulassung zum Modul	--
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Main Seminar 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Non-exhaustive list of topics for the seminar:</p> <ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	Students <ul style="list-style-type: none">• 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-67143 Advanced nonlinear optics	
Modulcode	FAU-67143
Modultitel (deutsch)	Advanced nonlinear optics
Modultitel (englisch)	Advanced nonlinear optics
Modul-Verantwortliche/r	Prof. Dr. Maria Chekhova (FAU) Dr. Hannieh Fattahi (FAU) Prof. Dr. Nicolas Joly (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>The goal of this lecture is to explore advanced concepts of nonlinear optics and their applications. This will cover the following topics:</p> <ul style="list-style-type: none"> • 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)

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	English

Modul FAU-67145 Waveguides, optical fibres and photonic crystal fibres	
Modulcode	FAU-67145
Modultitel (deutsch)	Waveguides, optical fibres and photonic crystal fibres
Modultitel (englisch)	Waveguides, optical fibres and photonic crystal fibres
Modul-Verantwortliche/r	Prof. Dr. Nicolas Joly (FAU) Prof. Dr.-Ing. Bernhard Schmauß (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture with exercises: Waveguides, optical fibres and photonic crystal fibres (4 SWS)
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	The students <ul style="list-style-type: none"> • 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

Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-67156 Quantum Computing	
Modulcode	FAU-67156
Modultitel (deutsch)	Quantum Computing
Modultitel (englisch)	Quantum Computing
Modul-Verantwortliche/r	Prof. Dr. Michael Hartmann (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Seminar 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p>

Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	The course will present all the relevant material. Useful additional reading contains <ul style="list-style-type: none"> • "Quantum Computation and Quantum Information by Nielsen and Chuang (Cambridge Univ. Press), • "Quantum Computing: 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 .
Unterrichtssprache	English

Modul FAU-713618 Computer Vision	
Modulcode	FAU-713618
Modultitel (deutsch)	Computer Vision
Modultitel (englisch)	Computer Vision
Modul-Verantwortliche/r	Prof. Dr. Bernhard Egger (FAU) Prof. Dr.-Ing. Andreas Maier (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.

Lern- und Qualifikationsziele	<p>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</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.
Unterrichtssprache	English

Modul FAU-763337 Laser Tissue Interaction	
Modulcode	FAU-763337
Modultitel (deutsch)	Laser Tissue Interaction
Modultitel (englisch)	Laser Tissue Interaction
Modul-Verantwortliche/r	Dr.-Ing. Florian Klämpfl (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.

Lern- und Qualifikationsziele	<p>The students can explain</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--
Empfohlene Literatur	--
Unterrichtssprache	Englisch

Modul FAU-901895 Deep Learning	
Modulcode	FAU-901895
Modultitel (deutsch)	Deep Learning
Modultitel (englisch)	Deep Learning
Modul-Verantwortliche/r	Felix Denzinger (FAU) Prof. Dr.-Ing. Andreas Maier (FAU) Fabian Wagner (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	None
Verwendbarkeit (Voraussetzung wofür)	--
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>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.</p> <p>This lecture introduces the core elements of neural networks and deep learning, it comprises:</p> <ul style="list-style-type: none"> • (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, ...) <p>The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.</p>
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Zulassung zur Modulprüfung	--
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	--

Empfohlene Literatur	<ul style="list-style-type: none">• 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)
Unterrichtssprache	English

Modul KIT-100386 Electromagnetics and Numerical Calculation of Fields	
Modulcode	KIT-100386
Modultitel (deutsch)	Electromagnetics and Numerical Calculation of Fields
Modultitel (englisch)	Electromagnetics and Numerical Calculation of Fields
Modul-Verantwortliche/r	Prof. Dr.-Ing. Thomas Zwick (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	

Inhalte

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.

Lern- und Qualifikationsziele	<p>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.</p> <p>The student will</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Success control is carried out in the form of a written test of 120 minutes.
Empfohlene Literatur	<ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul KIT-100430 Non-linear Optics	
Modulcode	KIT-100430
Modultitel (deutsch)	Non-linear Optics
Modultitel (englisch)	Non-linear Optics
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	2 SWS exercise 2 SWS lectures
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	60 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 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

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Empfohlene Literatur	<p>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.</p>
Unterrichtssprache	Englisch

Modul KIT-100435 Laser Physics	
Modulcode	KIT-100435
Modultitel (deutsch)	Laser Physics
Modultitel (englisch)	Laser Physics
Modul-Verantwortliche/r	Prof. Dr. Marc Eichhorn (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	2 SWS lectures, 2 SWS tutorial
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	55 h
- Selbststudium	95 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>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.</p> <p>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.</p> <p>Contents:</p> <ul style="list-style-type: none"> 1 Quantum-mechanical fundamentals of lasers <ul style="list-style-type: none"> 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 <ul style="list-style-type: none"> 2.1 Population inversion and feedback 2.2 Spectroscopic laser rate equations 2.3 Potential model of the laser 3 Optical Resonators <ul style="list-style-type: none"> 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 <ul style="list-style-type: none"> 4.1 Basics of Q-switching 4.2 Basics of mode locking and ultra-short pulses 5 Laser examples and their applications <ul style="list-style-type: none"> 5.1 Gas lasers: The Helium-Neon-Laser 5.2 Solid-state lasers <ul style="list-style-type: none"> 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 <ul style="list-style-type: none"> 5.3.1 Thermal lensing and thermal stress 5.3.2 The fiber laser 5.3.3 The thin-disk laser
Lern- und Qualifikationsziele	<p>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.</p>
Empfohlene Literatur	<p>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. Kneubühl, M. W. Sigrist, Laser (Teubner)</p>

Unterrichtssprache	Englisch
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Modul KIT-100436 Optical Transmitters and Receivers	
Modulcode	KIT-100436
Modultitel (deutsch)	Optical Transmitters and Receivers
Modultitel (englisch)	Optical Transmitters and Receivers
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium	135 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>The course concentrates on basic optical communication concepts and connects them with the properties of physical components. The following topics are discussed:</p> <ul style="list-style-type: none"> • Advantages and limitations of optical communication systems • Optical transmitters comprising lasers and modulators • Optical receivers comprising direct and heterodyne reception • Characterization of signal quality
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral examination (approx. 20 minutes). The individual dates for the oral examination are offered regularly.

Empfohlene Literatur	<ul style="list-style-type: none">• 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
Unterrichtssprache	Englisch

Modul KIT-100456 Optical Engineering	
Modulcode	KIT-100456
Modultitel (deutsch)	Optical Engineering
Modultitel (englisch)	Optical Engineering
Modul-Verantwortliche/r	Prof. Dr. Wilhelm Stork (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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:</p> <ul style="list-style-type: none"> • 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)

Lern- und Qualifikationsziele	<p>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.</p> <p>After the course, students will:</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Achievement will be examined in an oral examination (approx. 20 minutes).
Empfohlene Literatur	<ul style="list-style-type: none"> • E. Hecht: Optics • J.W. Goodman: Introduction to Fourier optics • K.K. Sharma: Optics - Principles and Applications
Unterrichtssprache	Englisch

Modul KIT-100506 Optical Waveguides and Fibers	
Modulcode	KIT-100506
Modultitel (deutsch)	Optical Waveguides and Fibers
Modultitel (englisch)	Optical Waveguides and Fibers
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Tutorium 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Introduction: Optical communications</p> <p>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.</p> <p>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.</p> <p>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</p> <p>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</p> <p>Waveguide-based devices: Modeling of dielectric waveguide structures using mode expansion and orthogonality relations, multimode interference couplers and directional couplers, waveguide gratings, material gain and absorption in optical waveguides, bent waveguides</p>

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: Oral exam Duration of Examination: approx. 20 minutes Modality of Exam: The written exam is offered continuously upon individual appointment.</p>
Empfohlene Literatur	<ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul KIT-100509 Optoelectronic Components	
Modulcode	KIT-100509
Modultitel (deutsch)	Optoelectronic Components
Modultitel (englisch)	Optoelectronic Components
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	90 h
- Selbststudium	210 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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:</p> <ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam

Empfohlene Literatur	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.
Unterrichtssprache	Englisch

Modul KIT-100512 Light and Display Engineering	
Modulcode	KIT-100512
Modultitel (deutsch)	Light and Display Engineering
Modultitel (englisch)	Light and Display Engineering
Modul-Verantwortliche/r	Dr.-Ing. Rainer Kling (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Tutorium 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Motivation: Light & Display Engineering</p> <p>Light, the Eye and the Visual System (including Melatonin)</p> <p>Fundamentals in Light Engineering</p> <p>Light in non - visual Processes (UV Processes)</p> <p>Color and Brightness</p> <p>Light Sources (Halogen, Low Pressure and High Pressure Lamps, LED Engines) and electronic Drivers</p> <p>Displays (Active and Passive Displays: AMOLED, E-ink, TFT Display, Plasma Display)</p> <p>Luminaries (Fundamentals, Design Rules, Simulations)</p> <p>Optical Design (Ray tracing, Reflector design, Computed Ray tracing)</p>

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: Oral exam</p> <p>Duration of Examination: approx. 25 minutes</p> <p>Modality of Exam: The oral exam is flexibly held by student request after the WS.</p>
Empfohlene Literatur	<ul style="list-style-type: none"> • Simons, Lighting Engineering: Applied Calculations, 2001 • Shunsuke Kobayashi: LCD Backlights, 2009 • Winchip, Fundamentals of Lighting, 2nd Edition, 2011 • Malacara, Handbook of Optical Design, 2004
Unterrichtssprache	Englisch

Modul KIT-100524 Solar Energy	
Modulcode	KIT-100524
Modultitel (deutsch)	Solar Energy
Modultitel (englisch)	Solar Energy
Modul-Verantwortliche/r	Prof. Dr. Bryce Sydney Richards (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 3 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium	120 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>The students:</p> <ul style="list-style-type: none"> • 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. <p>Die Studentinnen und Studenten können in englischer Fachsprache sehr gut kommunizieren.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: written exam Duration of Examination: 120 Minutes Modality of Exam: One written exam at the end of each semester.</p>
Zusätzliche Informationen zum Modul	
Empfohlene Literatur	<ul style="list-style-type: none"> • P. Würfel: Physics of Solar Cells • V. Quaschnig: Renewable Energy Systems • C. Honsberg and S. Bowden, PV Education CD-ROM and website, http://www.pveducation.org/pvcdrom
Unterrichtssprache	Englisch

Modul KIT-100566 Field Propagation and Coherence	
Modulcode	KIT-100566
Modultitel (deutsch)	Field Propagation and Coherence
Modultitel (englisch)	Field Propagation and Coherence
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS, Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>The following selection of topics will be presented:</p> <p>Light waves, modes and rays: Longitudinal and transverse modes, sampling theorem, counting and density of modes ("states")</p> <p>Propagation in multimode waveguides. Near-field and far-field. Impulse response and transfer function. Perutations and mode coupling.</p> <p>Multimode interference (MMI) coupler. Modal noise (speckle)</p> <p>Propagation in homogeneous media: Resolution limit. Non-paracial and paracial optics. Gaussian beam. ABCD matrix</p> <p>Coherence of optical fields: Coherence function and power spectrum. Polarisation, eigenstates and principal states.</p> <p>Measurement of coherence with interferometers (Mach-Zehnder, Michelson). Self-heterodyne and self-homodyne setups</p>

Lern- und Qualifikationsziele	<p>Presenting in a unified approach the common background of various problems and questions arising in general optics and optical communications</p> <p>The students</p> <p>know the common properties of counting of modes, density of states and the sampling theorem</p> <p>comprehend the relationship between propagation in multimode waveguides, mode coupling, MMI and speckles</p> <p>can analyze propagation in homogeneous media with respect to system theory, antennas, and the resolution limit of optical instruments</p> <p>understand that coherence as a general concept comprises coherence in time, in space and in polarisation</p> <p>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)</p> <p>can assess when can two incandescent bulbs form an interference pattern in time</p> <p>know under which conditions a heterodyne radio receiver, which is based on a non-stationary interference, actually works</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: oral exam</p> <p>Duration of Examination: approx. 30 minutes</p> <p>Modality of Exam: Oral examination, usually one examination day per month during the summer and winter terms. An extra questions-andanswers session will be held for preparation if students wish so.</p>
Empfohlene Literatur	<p>Detailed lecture notes as well as the presentation slides can be downloaded from the IPQ lecture pages.</p> <p>Additional reading:</p> <ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul KIT-100577 Lighting Design - Theory and Applications	
Modulcode	KIT-100577
Modultitel (deutsch)	Lighting Design - Theory and Applications
Modultitel (englisch)	Lighting Design - Theory and Applications
Modul-Verantwortliche/r	Dr.-Ing. Rainer Kling (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Seminar 3 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium	45 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 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) <ol style="list-style-type: none"> 7.1 Interior Lighting 7.2 Exterior lighting 7.3 Illumination Own Calculation Examples (Practical Part) Motivation: Light & Display Engineering 8) Own Calculation Examples (Practical Part) Motivation: Light & Display Engineering

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>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.</p>
Empfohlene Literatur	<ul style="list-style-type: none"> • 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, 2001 Simons, Lighting Engineering: Applied Calculations, 2001 • R. Winchip, Fundamentals of Lighting, 2nd Edition, 2011
Unterrichtssprache	Englisch

Modul KIT-101834 Business Innovation in Optics and Photonics	
Modulcode	KIT-101834
Modultitel (deutsch)	Business Innovation in Optics and Photonics
Modultitel (englisch)	Business Innovation in Optics and Photonics
Modul-Verantwortliche/r	Prof. Dr. Werner Nahm (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	34 h
- Selbststudium	86 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>This course is instructed and presented by external innovation specialists of the R&D, business and management departments of the Carl Zeiss AG.</p> <p>Introduction: Examples of existing smart mobile device applications, Brainstorming for ideas</p> <p>Technology Introduction: Mobile device technology, Optic components, Display technology (LCD, OLED), Tracking and Sensor Technologies in smart mobile devices</p> <p>Group Work Technology</p> <p>Group Presentations Technology</p> <p>Business Case Development/ Business Plan: Market segmentation, Market research, Essentials of finance, How to write a business plan?</p> <p>Management of Intellectual Property (IP): Importance of IP Management, Patent research, Patent claims, Licencing, Patent infringement, Patent litigation</p> <p>Project Design: How to run an agile R&D Project?, Target costing, Networked product development</p> <p>Agile project simulation</p> <p>Group Work</p> <p>Excursion to Carl Zeiss AG in Oberkochen (full day)</p> <p>Presentation of results of the group work to the new business experts committee of the Carl Zeiss AG</p>

Lern- und Qualifikationsziele	<p>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.</p> <p>The students can organize themselves in groups and distribute and execute tasks. Further they gain competences in the fields teamwork, organization and communication.</p> <p>The students</p> <ul style="list-style-type: none"> 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: examination of another type</p> <p>Duration of Examination: 4 group presentations à 20 minutes (approx.)</p> <p>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</p>
Unterrichtssprache	Englisch

Modul KIT-101900 Spectroscopic Methods	
Modulcode	KIT-101900
Modultitel (deutsch)	Spectroscopic Methods
Modultitel (englisch)	Spectroscopic Methods
Modul-Verantwortliche/r	Prof. Dr. Manfred Kappes (KIT) apl. Prof. Dr. Andreas-Neil Unterreiner (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 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 considerations, Stokes shift, Lippert equation, fluorescence anisotropy; confocal fluorescence microscopy, advanced microscopic 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

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> • 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)
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • Demtröder: Laser Spectroscopy, Rullière: Femtosecond Laser Pulses, Atkins: Molecular Quantum • Mechanics, various review articles
Unterrichtssprache	Englisch

Modul KIT-101901 Advanced Inorganic Materials	
Modulcode	KIT-101901
Modultitel (deutsch)	Advanced Inorganic Materials
Modultitel (englisch)	Advanced Inorganic Materials
Modul-Verantwortliche/r	Prof. Dr. Claus Feldmann (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium	45 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Selected aspects of modern functional inorganic materials, including:</p> <ul style="list-style-type: none"> • High-temperature ceramics and hard materials • Color pigments – from Egyptian 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

Lern- und Qualifikationsziele	<p>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-of-the-art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence) of inorganic functional materials.</p> <p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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).
Unterrichtssprache	Englisch

Modul KIT-101901 Advanced Inorganic Materials	
Modulcode	KIT-101901
Modultitel (deutsch)	Advanced Inorganic Materials
Modultitel (englisch)	Advanced Inorganic Materials
Modul-Verantwortliche/r	Prof. Dr. Claus Feldmann (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium	45 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Selected aspects of modern functional inorganic materials, including:</p> <ul style="list-style-type: none"> • 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 <p>... and other examples of advanced functional materials</p>

Lern- und Qualifikationsziele	<p>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-of-the-art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence) of inorganic functional materials.</p> <p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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).
Unterrichtssprache	Englisch

Modul KIT-101905 Imaging Techniques in Light Microscopy	
Modulcode	KIT-101905
Modultitel (deutsch)	Imaging Techniques in Light Microscopy
Modultitel (englisch)	Imaging Techniques in Light Microscopy
Modul-Verantwortliche/r	Prof. Dr. Martin Bastmeyer (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p> <ol style="list-style-type: none"> 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)

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Written exam over 120 minutes (depending on the number of participants oral exam over approx.45 min).</p> <p>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.</p>
Empfohlene Literatur	<p>Lecture presentations will be accessible in pdf-format Recent review articles will be distributed before the lectures</p> <p>Books:</p> <ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul KIT-101919 Fabrication and Characterisation of Optoelectronic Devices	
Modulcode	KIT-101919
Modultitel (deutsch)	Fabrication and Characterisation of Optoelectronic Devices
Modultitel (englisch)	Fabrication and Characterisation of Optoelectronic Devices
Modul-Verantwortliche/r	Prof. Dr. Bryce Sydney Richards (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 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) Characterisation: materials properties (electron microscopy, crystallinity, bonding energies, elemental 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)

Lern- und Qualifikationsziele	<p>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 technological-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.</p> <p>While fulfilling the learning targets, the students possess the basic knowledge about the working principles of optoelectronic devices;</p> <p>comprehend the boundary conditions for the design of optoelectronic devices and have a good understanding of the challenges in microfabrication</p> <p>are familiar with different lithographic techniques, including e-beam lithography, optical lithography, multiple-photon lithography, X-ray lithography, etc.</p> <p>comprehend the different techniques that are available for thin-film deposition of dielectrics, metals and semiconductors</p> <p>understand what role micro-optics can play in such devices</p> <p>be able to determine the most promising characterisation techniques for evaluating material quality, electronic properties, as well as optical and electrical performance.</p> <p>Exposure to different dry- and wet-etching processes to help realise device structures</p> <p>have an understanding of the economic implications of the chosen technologies and their compatibility with highthroughput production</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: written exam</p> <p>Duration of Examination: 120 Minutes</p> <p>Modality of Exam: One written exam offered at the end of each semester.</p>
Unterrichtssprache	Englisch

Modul KIT-101920 X-Ray Optics	
Modulcode	KIT-101920
Modultitel (deutsch)	X-Ray Optics
Modultitel (englisch)	X-Ray Optics
Modul-Verantwortliche/r	Dr. Arndt Last (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 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
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam

Empfohlene Literatur	A. Erko, M. Idir, Th. Krist and A. G. Michette (editors), Modern Developments in X-Ray and Neutron Optics
Unterrichtssprache	Englisch

Modul KIT-101921 Measurement and Control Systems	
Modulcode	KIT-101921
Modultitel (deutsch)	Measurement and Control Systems
Modultitel (englisch)	Measurement and Control Systems
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christoph Stiller (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	45 h
- Selbststudium	105 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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 exercise
Inhalte	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 exercise

Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none">• possess knowledge in the theory of linear time-invariant systems in time domain, state space, and frequency domain• can formulate as system 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written exam 120 min (100%)
Empfohlene Literatur	<p>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</p>
Unterrichtssprache	Englisch

Modul KIT-101923 Machine Vision	
Modulcode	KIT-101923
Modultitel (deutsch)	Machine Vision
Modultitel (englisch)	Machine Vision
Modul-Verantwortliche/r	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	8 LP
Arbeitsaufwand (work load) in:	240 h
- Präsenzstunden	60 h
- Selbststudium	180 h
(einschl. Prüfungsvorbereitungen)	

Inhalte

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 discussion 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 valuable 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. The 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.

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

Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Empfohlene Literatur	Main results are summarized in the slides that are made available as pdf-files. Further recommendations will be presented in the lecture.
Unterrichtssprache	Englisch

Modul KIT-101924 Solar Thermal Energy Systems	
Modulcode	KIT-101924
Modultitel (deutsch)	Solar Thermal Energy Systems
Modultitel (englisch)	Solar Thermal Energy Systems
Modul-Verantwortliche/r	apl. Prof. Dr. Ron Dagan (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture + tutorial 2 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	30 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>1) Introduction to solar energy: Energy resources, consumption and costs</p> <p>2) The sun as an energy resource: Structure of the sun, Black body radiation, solar constant, solar spectral distribution Sun-Earth geometrical relationship</p> <p>3) Passive and active solar thermal applications.</p> <p>4) Fundamentals of thermodynamics and heat transfer</p> <p>5) Solar thermal systems - solar collector-types, concentrating collectors, solar towers. Heat losses and efficiency</p> <p>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.</p>

Lern- und Qualifikationsziele	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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	oral exam of about 30 minutes
Empfohlene Literatur	<ul style="list-style-type: none">• Foster, Ghassemi, cota,; Solar Energy• Duffie and Beckman; Solar engineering of thermal processes• Holman.; Heat transfer• Heinzl; script to solar thermal energy (in German)
Unterrichtssprache	Englisch

Modul KIT-101931 Modern Physics	
Modulcode	KIT-101931
Modultitel (deutsch)	Modern Physics
Modultitel (englisch)	Modern Physics
Modul-Verantwortliche/r	apl. Prof. Dr. Bernd Pilawa (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	45 h
- Selbststudium	105 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ol style="list-style-type: none"> 1) Introduction 2) Electromagnetism 3) Special Relativity 4) Quantum mechanics 5) Atoms 6) Solids
Lern- und Qualifikationsziele	<p>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.</p> <p>Learning targets The students</p> <ul style="list-style-type: none"> • 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.

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	Paul A. Tipler: Physics for engineers and scientists Paul A. Tipler: Modern Physics
Unterrichtssprache	English

Modul KIT-102054 Condensed Matter Theory I, Fundamentals	
Modulcode	KIT-102054
Modultitel (deutsch)	Condensed Matter Theory I, Fundamentals
Modultitel (englisch)	Condensed Matter Theory I, Fundamentals
Modul-Verantwortliche/r	Prof. Dr. Markus Garst (KIT) Prof. Dr. Alexander Mirlin (KIT) Prof. Dr. Alexander Shnirman (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 4 h per week Exercise: 2 h per week
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	300 h 90 h 210 h
Inhalte	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: <ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral Exam. The total duration of the oral exam is approx. 60 minutes.
Empfohlene Literatur	<ul style="list-style-type: none"> • 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

Unterrichtssprache

Englisch

Modul KIT-102146 Nano-Optics	
Modulcode	KIT-102146
Modultitel (deutsch)	Nano-Optics
Modultitel (englisch)	Nano-Optics
Modul-Verantwortliche/r	Dr. Andreas Naber (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 4 h per week Exercise: 2 h per week
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	90 h
- Selbststudium	210 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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).
Lern- und Qualifikationsziele	The students <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min oral exam

Unterrichtssprache	Englisch
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Modul KIT-102280 Theoretical Optics	
Modulcode	KIT-102280
Modultitel (deutsch)	Theoretical Optics
Modultitel (englisch)	Theoretical Optics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	5 LP
Arbeitsaufwand (work load) in:	150 h
- Präsenzstunden	50 h
- Selbststudium	100 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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)

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • "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
Unterrichtssprache	Englisch

Modul KIT-102295 Theoretical Nanooptics	
Modulcode	KIT-102295
Modultitel (deutsch)	Theoretical Nanooptics
Modultitel (englisch)	Theoretical Nanooptics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium	135 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections.</p> <p>Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates.</p> <p>Properties of plasmonic nanoparticles and the ability to tune their properties</p> <p>Notion of optical antennas and the discussion of their basic characteristics</p> <p>Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays.</p> <p>Discussion of metamaterials (unit cells, homogenization, light propagation, applications)</p> <p>Transformation optics</p> <p>Analytical modeling and phenomenological tools to describe nanooptical systems</p>
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> 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

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral Exam. The total duration of the oral exam is approx. 60 minutes
Empfohlene Literatur	<ul style="list-style-type: none">• 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
Unterrichtssprache	Englisch

Modul KIT-102408 Solid-State Optics	
Modulcode	KIT-102408
Modultitel (deutsch)	Solid-State Optics
Modultitel (englisch)	Solid-State Optics
Modul-Verantwortliche/r	PD Dr. Michael Hetterich (KIT) Prof. Dr. Heinz Kalt (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS + exercise 2 SWS
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	300 h
- Präsenzstunden	90 h
- Selbststudium	210 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.

Lern- und Qualifikationsziele	<ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min oral exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul KIT-102693 Automotive Vision	
Modulcode	KIT-102693
Modultitel (deutsch)	Automotive Vision
Modultitel (englisch)	Automotive Vision
Modul-Verantwortliche/r	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 3 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium	135 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam

Empfohlene Literatur	TBA
Unterrichtssprache	Englisch

Modul KIT-103089 Computational Photonics, without ext. Exercises	
Modulcode	KIT-103089
Modultitel (deutsch)	Computational Photonics, without ext. Exercises
Modultitel (englisch)	Computational Photonics, without ext. Exercises
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	unregelmäßig, siehe gegebenenfalls zusätzliche Informationen
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium	120 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Transfer Matrix Method to describe the optical response from stratified media</p> <p>Finite Differences to characterize eigenmode in fiber waveguides</p> <p>Beam propagation method to describe the evolution of light in the realm of integrated optics</p> <p>Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D</p> <p>Mie Theory to describe the scattering of light from individual cylindrical or spherical objects</p> <p>Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems</p> <p>Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape</p> <p>Greens' Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background</p> <p>Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the surface</p>
Lern- und Qualifikationsziele	<p>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.</p>

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral Exam. The total duration of the oral exam is approx. 60 minutes.
Empfohlene Literatur	<ul style="list-style-type: none">• "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
Unterrichtssprache	Englisch

Modul KIT-103093 Quantum Optics	
Modulcode	KIT-103093
Modultitel (deutsch)	Quantum Optics
Modultitel (englisch)	Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS + Exercise class 2 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	90 h
- Selbststudium	90 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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.)

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> • 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.
Unterrichtssprache	Englisch

Modul KIT-103252 Optical Systems in Medicine and Life Science	
Modulcode	KIT-103252
Modultitel (deutsch)	Optical Systems in Medicine and Life Science
Modultitel (englisch)	Optical Systems in Medicine and Life Science
Modul-Verantwortliche/r	Prof. Dr. Werner Nahm (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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-Theory) Systems Design and Engineering: System architecture V-Model of Product Development Process</p>

Lern- und Qualifikationsziele	<p>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.</p> <p>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.</p> <p>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</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Empfohlene Literatur	M. Kaschke, Optical Devices in Ophthalmology and Optometry, Willey-VCH
Unterrichtssprache	Englisch

Modul KIT-103270 Optical Networks and Systems	
Modulcode	KIT-103270
Modultitel (deutsch)	Optical Networks and Systems
Modultitel (englisch)	Optical Networks and Systems
Modul-Verantwortliche/r	Prof. Dr.-Ing. Sebastian Randel (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p> <p>Access neetworks: fiber-to-the-X, passive optical networks (GPON, EPON, NG-PON2, WDM PON), statistical multiplexing vs. point-to-point</p> <p>Metro- and long-haul networks:</p> <p>System-design aspects: dense WDM (ITU grid), optical amplifiers, chromatic dispersion, coherent detection, optical vs. electronic impairment mitigation, capacity limits.</p> <p>Wavelength switching: wavelength selective switch (WSS), reconfigurable optical add-drop multiplexer (ROADM).</p> <p>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).</p> <p>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.</p>

Lern- und Qualifikationsziele	<p>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.</p> <p>The students</p> <ul style="list-style-type: none"> 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>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.</p>
Empfohlene Literatur	<p>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</p>
Unterrichtssprache	Englisch

Modul KIT-103450 Digital Signal Processing in Optical Communications - with Practical Exercises	
Modulcode	KIT-103450
Modultitel (deutsch)	Digital Signal Processing in Optical Communications - with Practical Exercises
Modultitel (englisch)	Digital Signal Processing in Optical Communications - with Practical Exercises
Modul-Verantwortliche/r	Prof. Dr.-Ing. Sebastian Randel (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS, Exercise class 2 SWS
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium	120 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p> <p>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.</p> <p>In the exercises, these function blocks are to be implemented in software (Matlab, Octave).</p> <p>In addition, individual examples show how digital signal processing algorithms are described in hardware (Hardware Description Language - HDL) and how their complexity scales.</p>

Lern- und Qualifikationsziele	<p>The students understand the functioning of modern optical communication systems, which combine electro-optical technologies with digital signal processing.</p> <p>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).</p> <p>Furthermore, they can estimate the influence of interfering effects occurring in the glass fiber such as chromatic dispersion and polarization mode dispersion.</p> <p>You are also able to estimate the complexity and power consumption of the resulting logic circuits.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>The exercise sheets and the oral questionnaire are used to rate other types of examinations. The overall impression is assessed. Duration about 20 minutes.</p>
Unterrichtssprache	Englisch

Modul KIT-103802 Adaptive Optics	
Modulcode	KIT-103802
Modultitel (deutsch)	Adaptive Optics
Modultitel (englisch)	Adaptive Optics
Modul-Verantwortliche/r	Prof. Dr. Ulrich Lemmer (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3 LP
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium	60 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>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.</p> <p>Theory of turbulence (covariances, structure functions, power spectra, inertial range, dimensional argument of Kolmogorov)</p> <p>Fourier optics (point-spread function, modulation transfer function)</p> <p>Statistical optics (characteristic function, probability density function)</p> <p>Sources and description of aberrations (Zernike polynomials, orthogonality, Marechal criterion)</p> <p>Adaptive optics systems (open- and closed-loop systems, error budgets, tip-tilt correction)</p> <p>Wavefront sensing (Shack-Hartmann wavefront sensor, wavefront reconstruction, wavefront-sensorless AO)</p> <p>Wavefront correction (tip-tilt mirrors, deformable mirrors, piezoelectric effect, microelectromechanical systems, electrostatic actuation)</p> <p>Simulation of adaptive optical systems (analytic vs. end-to-end modelling)</p> <p>Propagation of laser beams through atmospheric turbulence (Gaussian beams, Rytov theory, scintillation index, beam wander)</p> <p>Modelling of free-space optical communication systems (aperture averaging, mean signal-to-noise ratio, false-alarm rate and fade probability, bit error-rate)</p>
Lern- und Qualifikationsziele	<p>The students will:</p> <ul style="list-style-type: none"> 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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>Type of Examination: Oral examination</p> <p>Duration of Examination: approx. 30 Minutes</p> <p>Modality of Exam: The oral exam will be scheduled during the semester break.</p>
Empfohlene Literatur	<ul style="list-style-type: none"> • Robert K. Tyson, Principles of Adaptive Optics, CRC Press • Michael C. Roggemann, Byron M. Welsh, Imaging through Turbulence, CRC Press

Unterrichtssprache	Englisch
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Modul KIT-105914 Photonic Integrated Circuit Design and Applications	
Modulcode	KIT-105914
Modultitel (deutsch)	Photonic Integrated Circuit Design and Applications
Modultitel (englisch)	Photonic Integrated Circuit Design and Applications
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT) Prof. Dr.-Ing. Sebastian Randel (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	<p>Lecture inclusive Exercise class 2 SWS</p> <p>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.</p> <p>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.</p>
Leistungspunkte (ECTS credits)	6 LP
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	30 h
- Selbststudium	150 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>Lectures:</p> <p>Lecture 1: Introduction to silicon photonics</p> <p>Lecture 2: Silicon photonics – technology overview</p> <p>Lecture 3: Wave propagation in silicon photonic waveguides</p> <p>Lecture 4: Mode expansion and orthogonality</p> <p>Lecture 5: Coupled-mode theory</p> <p>Lecture 6: Selected passive devices</p> <p>Lecture 7: Modulators</p> <p>Lecture 8: Photodetectors</p> <p>Lecture 9: Optical amplifiers and lasers</p> <p>Lecture 10: Test and packaging</p> <p>Lecture 11: Optical communications</p> <p>Lecture 12: Optical metrology</p> <p>Lecture 13: Biophotonics and neurophotonics</p> <p>Lecture 14: Integrated quantum optics and optical computing</p> <p>Design lab:</p> <p>Problem Set 1: Mode fields and mode expansion</p> <p>Problem Set 2: Coupling efficiency and coupled-mode theory</p> <p>Design Project A: Optical filter</p> <p>Design Project B: Optical transceiver</p> <p>Design Project C: Optical communication link</p>
Lern- und Qualifikationsziele	<p>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.</p> <p>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.</p>

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	<p>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.</p> <p>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).</p> <p>The overall impression is rated.</p>
Unterrichtssprache	Englisch

Modul PAFMO002a Structure of Matter	
Modulcode	PAFMO002a
Modultitel (deutsch)	Structure of Matter
Modultitel (englisch)	Structure of Matter
Modul-Verantwortliche/r	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 4 h per week Exercise: 2 h per week
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	240 h
- Präsenzstunden	90 h
- Selbststudium	150 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>The students</p> <ul style="list-style-type: none"> • 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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (100%)
Empfohlene Literatur	Demtröder, "Experimental physics II" Demtröder, "Experimental physics III – atoms, molecules and solids" R. Feynman, "Feynman lectures on physics III quantum mechanics" Jackson, "Classical Electrodynamics" E. Hecht, "Optics"
Unterrichtssprache	Englisch

Modul PAFMO004a Laser Physics	
Modulcode	PAFMO004a
Modultitel (deutsch)	Laser Physics
Modultitel (englisch)	Laser Physics
Modul-Verantwortliche/r	Prof. Dr. J. Limpert (FSU), Prof. Dr. S. Nolte (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 4 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in:	240 h
- Präsenzstunden	90 h
- Selbststudium	150 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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.
Lern- und Qualifikationsziele	<p>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</p>
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.
Unterrichtssprache	Englisch

Modul PAFMO005 Optical Metrology and Sensing	
Modulcode	PAFMO005
Modultitel (deutsch)	Optical Metrology and Sensing
Modultitel (englisch)	Optical Metrology and Sensing
Modul-Verantwortliche/r	Prof. Dr. Isabelle Staude (FSU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>The students understand the basic principles and wave optical fundamentals of optical metrology are familiar with key sensor technologies and measurement techniques</p> <p>can apply interferometry, holography, and speckle methods for precise measurements understand phase retrieval and its role in optical metrology</p> <p>can analyze and compare metrology techniques for aspheres, freeform surfaces, and confocal methods</p>

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	
Unterrichtssprache	Englisch

Modul PAFMO006 Introduction to Optical Modeling	
Modulcode	PAFMO006
Modultitel (deutsch)	Introduction to Optical Modeling
Modultitel (englisch)	Introduction to Optical Modeling
Modul-Verantwortliche/r	Prof. Dr. F. Wyrowski (FSU), apl. Prof. Dr. U. W. Zeitner (FSU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 628 M.Sc. Photonics: compulsory module 128 MSc. Physics specialisation „Optics“: required elective module
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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.

Unterrichtssprache	Englisch
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Modul PAFMO122 Biophotonics	
Modulcode	PAFMO122
Modultitel (deutsch)	Biophotonics
Modultitel (englisch)	Biophotonics
Modul-Verantwortliche/r	Prof. Dr. Rainer Heintzmann (FSU), Prof. Dr. Ralf Ehrlich (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>The Module provides a deep introduction into the multitude of possible linear and non-linear light biological matter interaction phenomena and thus in modern techniques and applications of frequency-, spatially-, and time-resolved bio-spectroscopy. The course presents a comprehensive overview over modern spectroscopic and optical imaging techniques inclusive specific theoretical methodologies to analyze the experimental spectroscopic data to resolve problems in life sciences. The biological part introduces to molecular and cellular properties of living organisms. It explains the basic structures and functions of prokaryotic and eukaryotic cells as well as the most important biochemical substance classes and biochemical pathways where they are involved. Furthermore, basics in microbiology, especially in antimicrobial resistant bacteria will be provided and combined with the introduction of diagnostic principles and selected infectious diseases. Examples for molecular and serological assay and test development and basic methods for diagnostics and epidemiology will be discussed. This sets the stage for biophotonic applications by showing several examples of how biophotonics can help to shed light on biologically and clinically relevant processes. The Module spans aspects of the scientific disciplines chemistry, physics, biology and medicine. The Exercises will be partly calculating examples and partly in the form a seminar talks of the students presenting current research publications. Intended learning outcomes: The aim of this course is to present modern methods in spectroscopy, microscopy, molecular biology, microbiology and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonics problems.</p>
Lern- und Qualifikationsziele	<p>The aim of this course is to present modern methods in spectroscopy, microscopy and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonic problems.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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
Unterrichtssprache	Englisch

Modul PAFMO129 Computational Imaging	
Modulcode	PAFMO129
Modultitel (deutsch)	Computational Imaging
Modultitel (englisch)	Computational Imaging
Modul-Verantwortliche/r	Prof. Dr. Rainer Heintzmann (FSU), Dr. Lars Lötgering (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Programming Lab: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	

Inhalte	<p>Review: Linear Algebra, Calculus, Python</p> <ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	Understanding the interplay between forward and inverse modeling in optical systems. Hands-on programming skills.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	A list of Literature and materials will be provided at the beginning of the semester.
Empfohlene Literatur	A list of Literature and materials will be provided at the beginning of the semester.
Unterrichtssprache	Englisch

Modul PAFMO130 Computational Photonics	
Modulcode	PAFMO130
Modultitel (deutsch)	Computational Photonics
Modultitel (englisch)	Computational Photonics
Modul-Verantwortliche/r	Prof. Dr. T. Pertsch (FSU)
Empfohlene bzw. erwartete Vorkenntnisse	Basic knowledge of a computer programming language and computational physics will be helpful.
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	schriftliche Prüfung (100%)
Zusätzliche Informationen zum Modul	Taflove and S.C. Hagness, Computational Electrodynamics
Empfohlene Literatur	Taflove and S.C. Hagness, Computational Electrodynamics

Unterrichtssprache	Englisch
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Modul PAFMO151 Experimental Nonlinear Optics	
Modulcode	PAFMO151
Modultitel (deutsch)	Experimental Nonlinear Optics
Modultitel (englisch)	Experimental Nonlinear Optics
Modul-Verantwortliche/r	Prof. Dr. G. G. Paulus (FSU)
Voraussetzung für die Zulassung zum Modul	-
Empfohlene bzw. erwartete Vorkenntnisse	-
Verwendbarkeit (Voraussetzung wofür)	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>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</p> <p>grasp the concept of phase-matching and its importance in nonlinear optical processes</p> <p>are familiar with ultrashort pulse propagation and high-harmonic generation</p> <p>can explain soliton formation and its relevance in nonlinear optics</p>
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	128 M.Sc. Physics: Required elective module (Specialization in „Optics“)
Empfohlene Literatur	
Unterrichtssprache	Englisch

Modul PAFMO160 Fiber Optics	
Modulcode	PAFMO160
Modultitel (deutsch)	Fiber Optics
Modultitel (englisch)	Fiber Optics
Modul-Verantwortliche/r	Prof. Dr. M. Schmidt (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>Students</p> <p>understand the fundamental properties and light propagation in optical fibers</p> <p>are familiar with fiber fabrication, characterization techniques, and special fiber types</p> <p>can analyze fiber-based devices such as amplifiers and lasers</p> <p>understand key applications of optical fibers in communication, sensing, and laser technology</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • Snyder/Love, Optical Waveguide Theory; • Okamoto, Fundamentals of Optical Waveguides.

Unterrichtssprache	Englisch
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Modul PAFMO170 High-Intensity/Relativistic Optics	
Modulcode	PAFMO170
Modultitel (deutsch)	High-Intensity/Relativistic Optics
Modultitel (englisch)	High-Intensity/Relativistic Optics
Modul-Verantwortliche/r	Prof. Dr. M. Kaluza (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • High-intensity laser technology; • Laser plasma physics; • Laser accelerated particles and applications.
Lern- und Qualifikationsziele	<p>The students understand the principles of high-intensity laser technology and its key components are familiar with laser-plasma interactions and their physical foundations</p> <p>can analyze laser-driven particle acceleration and its applications in science and technology</p>
Voraussetzung für die Zulassung zur Modulprüfung	keine
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	<ul style="list-style-type: none"> • 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).
Unterrichtssprache	Englisch

Modul PAFMO180 Image Processing	
Modulcode	PAFMO180
Modultitel (deutsch)	Image Processing
Modultitel (englisch)	Image Processing
Modul-Verantwortliche/r	Prof. Dr. Joachim Denzler (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 M.Sc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	Gonzalez, Woods, Digital Image Processing, Prentice Hall, 2001

Unterrichtssprache	Englisch
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Modul PAFMO181 Image Processing in Microscopy	
Modulcode	PAFMO181
Modultitel (deutsch)	Image Processing in Microscopy
Modultitel (englisch)	Image Processing in Microscopy
Modul-Verantwortliche/r	Prof. Dr. Rainer Heintzmann (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	All the image processing and simulations will be practiced in exercises. The student needs to be familiar with programming at a basic level and with basic concepts of image processing such as filtering and thresholding. The Image Processing lecture by Prof. Denzler in the second term forms a good basis for this course.
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	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.
Lern- und Qualifikationsziele	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).

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
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Unterrichtssprache	Englisch
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Modul PAFMO183 Introduction to Nanooptics	
Modulcode	PAFMO183
Modultitel (deutsch)	Introduction to Nanooptics
Modultitel (englisch)	Introduction to Nanooptics
Modul-Verantwortliche/r	Prof. Dr. I. Staude (FSU), Prof. Dr. T. Pertsch (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on modern optics and condensed matter physics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • Surface-plasmon-polaritons; • Plasmonics; • Photonic crystals; • Fabrication and optical characterization of nanostructures; • Photonic nanomaterials / metamaterials / metasurfaces; • Optical nanoemitters; • Optical nanoantennas.
Lern- und Qualifikationsziele	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.

Voraussetzung für die Zulassung zur Modulprüfung	Keine
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	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.
Unterrichtssprache	Englisch

Modul PAFMO184 Integrated Optics	
Modulcode	PAFMO184
Modultitel (deutsch)	Integrated Optics
Modultitel (englisch)	Integrated Optics
Modul-Verantwortliche/r	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Verwendbarkeit (Voraussetzung wofür)	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture 2 SWS and exercise 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	The lecture will cover a significant part of integrated quantum photonics, which is one of the pillars of the current quantum technology development. In particular, the lecture will cover the following topics <ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>The course should provide the participating students with a profound knowledge on the state of the art of integrated optics used for the realization of quantum optical devices.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of integrated quantum photonics and will be able to develop own concepts for integrated quantum circuitry.</p> <p>The intended learning outcome is that the students are introduced to the basics on the field of integrated quantum optics and its applications. Therefore, course starts with an overview on the generation of non-classical states of light with special attention on integrated solutions. Afterwards several integrated photonic platforms will be discussed ranging from fabrication to performance and useability.</p> <p>Based on that the on-chip manipulation of non-classical states of light will be discussed. This starts with the very general concept of quantum walks and continues towards quantum simulation. It ends with an introductory to photonic quantum computing with a clear focus on practical implementation of quantum photonic gate structures.</p> <p>The course closes with the discussion on non-classical light detection in integrated photonics.</p>
Voraussetzung für die Zulassung zur Modulprüfung	
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	A list of literature and materials will be provided at the beginning of the semester.
Unterrichtssprache	Englisch

Modul PAFMO185 Innovation Methods in Photonics	
Modulcode	PAFMO185
Modultitel (deutsch)	Innovation Methods in Photonics
Modultitel (englisch)	Innovation Methods in Photonics
Modul-Verantwortliche/r	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics specialisation „Optics“: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>The students will learn how the results of their scientific research can be turned into relevant innovations as an important part of their future career. On the one hand, the course will enable students to understand and to drive innovation processes in photonics companies. On the other hand, students will develop an entrepreneurial skill set for the independent economical exploitation of scientific ideas.</p> <p>Therefore, the course introduces the basic knowledge on innovation management, entrepreneurship, and intellectual property rights. To practice their skills, the students will also conduct their own photonics innovation project during the semester by working hands-on in small teams in the photonics makerspace Lichtwerkstatt. During this practical part, they acquire and apply a thorough knowledge of photonic rapid prototyping technologies (e.g. 3d- scanning and printing, laser cutting, microcontrollers, ...) and the most important creativity methods and project management skills. To cover this range of topics, the course will be supported by guest lecturers from different sectors (academia, industry).</p>

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	A list of literature and materials will be provided at the beginning of the semester.
Unterrichtssprache	English

Modul PAFMO205 Light Microscopy	
Modulcode	PAFMO205
Modultitel (deutsch)	Light Microscopy
Modultitel (englisch)	Light Microscopy
Modul-Verantwortliche/r	Prof. Dr. R. Heintzmann
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 M.Sc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>Starting from geometrical optics the imaging system will be described and optical aberrations will be discussed. Moving on to wave optics monochromatic waves will be taken as the basis for the description of coherent imaging. Combined with scattering theory in the 1st Born approximation a fundamental understanding of the possibilities and limitations in imaging is gained. The concept of the amplitude transfer function and McCutchens 3-dimensional pupil function are introduced. On this basis various coherent imaging modes are discussed including holographic approaches and their limitations, and optical coherent tomography.</p> <p>The working principles of light-detectors are discussed and the requirements for appropriate sampling of images.</p> <p>Finally various modes of fluorescence microscopy and high-resolution microscopy will be covered.</p> <p>The exercises will be calculating examples, also involving hands-on computer based modeling using Matlab and other tools.</p>

Lern- und Qualifikationsziele	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
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Unterrichtssprache	Englisch

Modul PAFMO220 Micro/Nanotechnology	
Modulcode	PAFMO220
Modultitel (deutsch)	Micro/Nanotechnology
Modultitel (englisch)	Micro/Nanotechnology
Modul-Verantwortliche/r	Apl. Prof. Uwe Zeitner
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Unterrichtssprache	Englisch

Modul PAFMO221 Microscopy	
Modulcode	PAFMO221
Modultitel (deutsch)	Microscopy
Modultitel (englisch)	Microscopy
Modul-Verantwortliche/r	Prof. Dr. R. Heintzmann, Prof. Dr. C. Eggeling
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • Optical microscopy • Circumventing the resolution limit • Electron microscopy • Atomic force microscopy
Lern- und Qualifikationsziele	This Module provides an introduction into the fundamentals of modern light and electron microscopy and enables the students to solve related problems.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Unterrichtssprache	Englisch

Modul PAFMO260 Quantum Optics	
Modulcode	PAFMO260
Modultitel (deutsch)	Quantum Optics
Modultitel (englisch)	Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. T. Pertsch, PD Dr. F. Setzpfandt
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on quantum theory and theoretical optics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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.
Lern- und Qualifikationsziele	<p>The course will give a basic introduction into the theoretical description of quantized light and quantized light-matter interaction. The derived formalism is then used to examine the properties of quantized light and to understand a number of peculiar quantum optical effects.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum optics and will be able to apply the derived formalism to other problems.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam

Empfohlene Literatur	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".
Unterrichtssprache	Englisch

Modul PAFMO261 Quantum Computing	
Modulcode	PAFMO261
Modultitel (deutsch)	Quantum Computing
Modultitel (englisch)	Quantum Computing
Modul-Verantwortliche/r	Prof. Dr. F. Steinlechner, Dr. F. Eilenberger, Prof. Dr. T. Pertsch
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „specialisation“: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>After active participation in the course, the students will be familiar with the basic concepts of quantum computation and the implementation of quantum algorithms. They will be able to apply their knowledge in the assessment and creation of quantum algorithms and the development of quantum information systems.</p> <p>The intended learning outcome is to introduce the students to the basic usage of quantum bits for information processing. To provide further insight, the course will expand this concept on multipartite systems and introduce the concept of entanglement.</p> <p>In a further step we shall see how individual quantum operations tie together to create algorithms. Important algorithms, such as the quantum Fourier transformation, the algorithms of Shor and Grover will be discussed. To relate the abstract knowledge on quantum algorithms to practical applications, real-world implementations of quantum computers will be discussed.</p>

Voraussetzung für die Zulassung zur Modulprüfung	
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	A list of literature and materials will be provided at the beginning of the semester.
Unterrichtssprache	English

Modul PAFMO262 Quantum Communicaton	
Modulcode	PAFMO262
Modultitel (deutsch)	Quantum Communicaton
Modultitel (englisch)	Quantum Communicaton
Modul-Verantwortliche/r	Prof. Dr. F. Steinlechner, Dr. F. Eilenberger, Prof. Dr. A. Tünnermann
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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;
Lern- und Qualifikationsziele	<p>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.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.</p>
Voraussetzung für die Zulassung zur Modulprüfung	

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Empfohlene Literatur	
Unterrichtssprache	English

Modul PAFMO263 Quantum Imaging and Sensing	
Modulcode	PAFMO263
Modultitel (deutsch)	Quantum Imaging and Sensing
Modultitel (englisch)	Quantum Imaging and Sensing
Modul-Verantwortliche/r	Dr. M. Gräfe (FSU), Dr. F. Setzpfandt (FSU), Prof. Dr. A. Tünnermann (FSU)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics specialisation „Optics“: required elective module 628 M.Sc. Photonics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	<p>Goals: The course will give a basic introduction into the usage of quantum light, in particular photon pairs, for imaging and sensing. To this end, many basic concepts and applications will be introduced and discussed. Furthermore, students will learn how to mathematically describe quantum sensing schemes in order to understand and predict their properties.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum imaging and sensing and will be able to apply the derived formalism to similar problems.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Empfohlene Literatur	A list of literature and materials will be provided at the beginning of the semester.
Unterrichtssprache	English

Modul PAFMO265 Semiconductor Nanomaterials	
Modulcode	PAFMO265
Modultitel (deutsch)	Semiconductor Nanomaterials
Modultitel (englisch)	Semiconductor Nanomaterials
Modul-Verantwortliche/r	Prof. Dr. I. Staude
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on modern optics and condensed matter physics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	The course will cover the following topics: <ul style="list-style-type: none"> • 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

Lern- und Qualifikationsziele	<p>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.</p>
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination at the end of the semester and oral presentation on a current research topic
Empfohlene Literatur	<p>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</p>
Unterrichtssprache	English

Modul PAFMO266 Strong-Field Laser Physics	
Modulcode	PAFMO266
Modultitel (deutsch)	Strong-Field Laser Physics
Modultitel (englisch)	Strong-Field Laser Physics
Modul-Verantwortliche/r	Prof. Dr. G. G. Paulus
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • charakteristische Größen in der Starkfeld-Laserphysik • charakteristische Effekte • theoretische Beschreibung der Elektronendynamik • die Rückstreuung als fundamentaler Prozess in der Starkfeld- und Attosekunden-Laserphysik • Erzeugung von Attosekunden-Pulsen • Messung von Attosekunden-Pulsen
Lern- und Qualifikationsziele	<ul style="list-style-type: none"> • Vermittlung von Kenntnissen zu den Grundlagen der Starkfeld-Laserphysik und der darauf aufbauenden Attosekunden-Laserphysik. • Entwicklung von Fähigkeiten zur selbständigen Behandlung von Fragestellungen dieser Felder.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	mündliche Prüfung (100%)
Zusätzliche Informationen zum Modul	
Empfohlene Literatur	Review-Artikel Z. Chang: Fundamentals of Attosecond Optics
Unterrichtssprache	Englisch

Modul PAFMO270 Theory of Nonlinear Optics	
Modulcode	PAFMO270
Modultitel (deutsch)	Theory of Nonlinear Optics
Modultitel (englisch)	Theory of Nonlinear Optics
Modul-Verantwortliche/r	Prof. Dr. U. Peschel
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 M.Sc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<ul style="list-style-type: none"> • 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.
Lern- und Qualifikationsziele	The course provides the theoretical background of non-linear optics and quantum optics.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (100 %). Written examination (100 %). The final grade will be determined by the exercise performance (25%)and an oral exam (75%).
Zusätzliche Informationen zum Modul	
Empfohlene Literatur	<ul style="list-style-type: none"> • Agrawal, Govind P.: Contemporary non-linear optics; • Moloney, Jerome V., Newell Alan C.: Non-Linear Optics ; • Sutherland, Richard Lee: Handbook of non-linear optics.
Unterrichtssprache	Englisch

Modul PAFMO271 Thin Film Optics	
Modulcode	PAFMO271
Modultitel (deutsch)	Thin Film Optics
Modultitel (englisch)	Thin Film Optics
Modul-Verantwortliche/r	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • Basic dispersion models in Thin Film Optics • Optical properties of material mixtures • Interfaces: Fresnel's 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
Lern- und Qualifikationsziele	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.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	schriftliche Prüfung (100%)

Zusätzliche Informationen zum Modul	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).
Empfohlene Literatur	<ul style="list-style-type: none">• 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.
Unterrichtssprache	Englisch

Modul PAFMO272 Terahertz Technology	
Modulcode	PAFMO272
Modultitel (deutsch)	Terahertz Technology
Modultitel (englisch)	Terahertz Technology
Modul-Verantwortliche/r	Prof. Dr. Gerhard G. Paulus
Voraussetzung für die Zulassung zum Modul	Keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 M.Sc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 h per week Exercise: 1 h per week
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	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.
Voraussetzung für die Zulassung zur Modulprüfung	Abgabe von Übungsaufgaben (Art und Umfang wird zu Semesterbeginn bekannt gegeben)
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	exam (100%) The module grade will consist of graded practice assignments and a written exam or oral presentation.
Zusätzliche Informationen zum Modul	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).

Empfohlene Literatur	<ul style="list-style-type: none">• 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
Unterrichtssprache	Englisch

Modul PAFMO280 Ultrafast Optics	
Modulcode	PAFMO280
Modultitel (deutsch)	Ultrafast Optics
Modultitel (englisch)	Ultrafast Optics
Modul-Verantwortliche/r	Prof. Dr. S. Nolte
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	Basic knowledge in laser physics.
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Wintersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • Introduction to ultrafast optics; • Fundamentals; • Ultrashort pulse generation; • Amplification of ultrashort pulses; • Measurement of ultrashort pulses; • Applications; • Generation of attosecond pulses.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	Vortrag
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	schriftliche oder mündliche Prüfung (100%) Prüfungsform wird zu Beginn des Semesters bekannt gegeben.

Zusätzliche Informationen zum Modul	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).
Empfohlene Literatur	<ul style="list-style-type: none">• Weiner, Ultrafast Optics;• Diels/Rudolph, Ultrashort Laser Pulse Phenomena;• Rulliere, Femtosecond laser pulses;• W. Koechner, Solid-state Laser engineering;• A. Siegman, Lasers.
Unterrichtssprache	Englisch

Modul PAFMO281 Ultrafast Fibre Laser: Technology and Applications	
Modulcode	PAFMO281
Modultitel (deutsch)	Ultrafast Fibre Laser: Technology and Applications
Modultitel (englisch)	Ultrafast Fibre Laser: Technology and Applications
Modul-Verantwortliche/r	Prof. Dr. Markus Schmidt (FSU), Dr. Maria Chernysheva (FSU)
Empfohlene bzw. erwartete Vorkenntnisse	Fiber Optics and Ultrafast Optics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics“: required elective module 628 MSc Photonics: required elective module
Häufigkeit des Angebots (Modulturnus)	jedes 2. Semester (ab Sommersemester)
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Lecture: 2 SWS Exercises: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium	75 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> • Review of fundamentals of ultrafast fibre lasers (mode-locking and Q-switching) • Engineering of fibre laser cavities • Ultrashort pulse characterization (autocorrelation, FROG, dispersive Fourier transformation, etc.) • Extreme phenomena, exploration of new wavelength ranges and other latest technology advancements in ultrafast fibre laser development • Detailed overview of the ultrafast laser applications in industry, sensing, and medicine (diagnostics and treatment)

Lern- und Qualifikationsziele	<p>The aim of the course is to deliver a comprehensive understanding on applied ultrafast laser technology, provide a comparison of solid-state, semiconductor and fibre systems with the focus on the latter, and introduce their modern industrial applications and various research areas.</p> <p>The course, first, will shortly review the basics of fibre optics, rare-earth ion spectroscopy, materials for saturable absorbers and fast modulation techniques, and a variety of operational regimes. The first part of the course will be summarized in pathways towards expected further advancements in the field, covering new research trends, expansion of operation wavelength and operational modalities along with the comparison to existing ultrafast laser technologies.</p> <p>The second and the largest part of the course will be dedicated to the discussion of the existing and emerging applications of ultrafast fibre lasers, including analysis of the corresponding performance requirements and technological goals for a specific application. Starting with high-power industrial applications for material processing, the course will discuss strategies for a further expansion of the ultrafast fibre laser systems towards a more diverse range of applications. These include diagnostics and treatment in medicine, neuroscience field and especially optogenetics, scientific applications for nuclear physics, sensing, metrology and security applications.</p> <p>As the result, students will receive a detailed overview of the road map of the ultrafast fibre laser technology development with further perspectives to employ the knowledge and prospects in their future careers. This will be strengthened during accompanying seminars on latest reported advancements and exercises with practical examples of laser systems.</p>
Voraussetzung für die Zulassung zur Modulprüfung	Completion of the exercises (exact extend will be announced at the beginning of the module)
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written or oral examination (100%) The specific form of the exam will be announced at the beginning of the semester.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Literature will be announced at the beginning of the semester
Unterrichtssprache	English

Modul PAFMO290 XUV and X-Ray Optics	
Modulcode	PAFMO290
Modultitel (deutsch)	XUV and X-Ray Optics
Modultitel (englisch)	XUV and X-Ray Optics
Modul-Verantwortliche/r	Prof. Dr. C. Spielmann (FSU), Dr. D. Kartashov (FSU)
Voraussetzung für die Zulassung zum Modul	Keine
Empfohlene bzw. erwartete Vorkenntnisse	keine
Verwendbarkeit (Voraussetzung wofür)	keine
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physik Vertiefung „Optik“: Wahlpflichtmodul 628 M.Sc. Photonics: Wahlpflichtmodul
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	Vorlesung: 2 SWS Übung: 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	120 h 45 h 75 h
Inhalte	<ul style="list-style-type: none"> • 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
Lern- und Qualifikationsziele	This course covers the fundamentals of modern optics at short wavelengths as they are necessary for the design of EUV and X-ray optical elements. Based on this the students will learn essentials of several challenging applications of short-wavelength optics, being actual in modern science and technology, including XUV- and X-ray microscopy.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	schriftliche oder mündliche Prüfung (100%)

Unterrichtssprache	Englisch
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Modul CORE-MT-01 Masterarbeit Photon Science and Technology	
Modulcode	CORE-MT-01
Modultitel (deutsch)	Masterarbeit Photon Science and Technology
Modultitel (englisch)	Master thesis
Modul-Verantwortliche/r	N. Joly (FAU), I. Staude (FSU), C. Rockstuhl (KIT)
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	828 MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	jedes Semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, ...)	<p>Practical course. total workload: 900 h depending on the topic this total workload should be distributed approximately as:</p> <ul style="list-style-type: none"> • 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
Leistungspunkte (ECTS credits)	30 LP
Arbeitsaufwand (work load) in:	900 h
- Präsenzstunden	0 h
- Selbststudium	900 h
(einschl. Prüfungsvorbereitungen)	
Inhalte	<p>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.</p> <p>Committee meetings with the student take place at the beginning of the thesis work and shortly before finalizing of the thesis research work.</p>
Lern- und Qualifikationsziele	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).
Voraussetzung für die Zulassung zur Modulprüfung	Students conduct 900 hours of research work including preparation, lab work, thesis writing and presentations.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	s. §19 Study Regulations

Zusätzliche Informationen zum Modul	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
Unterrichtssprache	Englisch
Unterrichtssprache	EnglisCh

Abkürzungen:

Abkürzungen für Veranstaltungen

AVL....	Antrittsvorlesung
AG....	Arbeitsgemeinschaft
AM....	Aufbaumodul
AS....	Ausstellung
BM....	Basismodul
BzPS....	Begleitveranstaltung zum Praxissemester
B....	Beratung
Bes....	Besichtigung
KB....	Besprechung
Blo....	Blockierung
BV....	Blockveranstaltung
DV....	Diavortrag
EF....	Einführungsveranstaltung
ES....	Einschreibungen
EKK....	Examensklausurenkurs
EX....	Exkursion
Exp....	Experiment/Erhebung
FE....	Feier/Festveranstaltung
F....	Filmvorführung
GÜ....	Geländeübung
GK....	Grundkurs
HpS....	Hauptseminar
HS/B....	Hauptseminar/Blockveranstaltung
HS/Ü....	Hauptseminar/Übung
Inf....	Informationsveranstaltung
IHS/ Ü....	Interdisziplinäres Hauptseminar/ Übung
KS....	Klausur
KS/ PR....	Klausur/Prüfung
K....	Kolloquium
K/P....	Kolloquium/Praktikum
KS....	Konferenz/Symposium
kV....	Kulturelle Veranstaltung
Ku....	Kurs

Abkürzungen für Veranstaltungen

Ku....	Kurs
Lag....	Lagerung
LFP....	Lehrforschungsprojekt
Lek....	Lektürekurs
M....	Modul
MV....	Musikveranstaltung
OS....	Oberseminar
OnLS....	Online-Seminar
OnV....	Online-Vorlesung
P....	Praktikum
PrS....	Praktikum/Seminar
PM....	Praxismodul
Pr....	Probe
PJ....	Projekt
PPD....	Propädeutikum
PS....	Proseminar
PR....	Prüfung
PrVo....	Prüfungsvorbereitung
QB....	Querschnittsbereich
RE....	Repetitorium
V/R....	Ringvorlesung
SU....	Schulung
S....	Seminar
S/E....	Seminar/Exkursion
S/Ü....	Seminar/Übung
SZ....	Servicezeit
Sl....	Sitzung
SoSch....	Sommerschule
SO....	Sonstiges
SV....	Sonstige Veranstaltung
SK....	Sprachkurs
TG....	Tagung
TT....	Teleteaching
TN....	Treffen
Tu....	Tutorium
T....	Tutorium
Ü....	Übung
Ü/B....	Übung/Blockveranstaltung
Ü....	Übungen
Ü/l....	Übung/Interdisziplinär

Abkürzungen für Veranstaltungen

Ü/P....	Übung/Praktikum
Ü/T....	Übung/Tutorium
Ve....	Versammlung
ViKo....	Videokonferenz
V....	Vorlesung
V/K....	Vorlesung m. Kolloquium
V/P....	Vorlesung/Praktikum
V/S....	Vorlesung/Seminar
V/Ü....	Vorlesung/Übung
Vor....	Vortrag
VT....	Vortrag
WS....	Wahlseminar
WV....	Wahlvorlesung
We....	Weiterbildung
Wo....	Workshop
WOS....	Workshop
ZÜ....	Zeugnisübergabe

Other Abbreviations

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