ENTWURF

Modulkatalog

des gemeinsamen Studienganges

M.Sc. Photon Science and Technology

durchgeführt von

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)
Friedrich-Schiller-Universität Jena (FSU)
Karlsruher Institut für Technologie (KIT)

Präambel

Der Studiengang „Photon Science and Technology M.Sc." ist in Deutschland einzigartig. Erstmalig führen drei Hochschulen aus drei verschiedenen Bundesländern gemeinsam ein Studienprogramm durch, um eine Spitzenausbildung auf dem Zukunftsfeld Photonik zu schaffen durch Synergien und Ausnutzen individueller fachlicher Stärken. Die Friedrich-Schiller-Universität Jena (FSU), die Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) und das Karlsruher Institut für Technologie (KIT) kooperieren schon seit Jahren im Rahmen der deutschlandweiten integrierten Graduiertenschule „Max Planck School of Photonics" (MPSP). Hierbei handelt es sich um ein Programm, das sich an die weltweit besten und geeignetsten Bewerberinnen und Bewerber richtet und diesen eine frühzeitige Orientierung zur Spitzenforschung bereits nach dem Bachelor ermöglicht. Um die Studierenden gemeinsam auszubilden und bestmöglichen Zugang zu den Ausbildungsmöglichkeiten an allen drei Hochschulen zu ermöglichen, soll dieser Kooperationsstudiengang eingerichtet werden. Für die herausragendsten Kandidaten und Kandidatinnen soll der neue Studiengang die Attraktivität des Standortes Deutschland stärken, da die individuelle Exzellenz durch den Betrieb eines gemeinsamen Elitestudienganges in kooperativer Verantwortung unterstrichen wird.

Das Studienprogramm ist forschungsorientiert und fokussiert auf das Erlangen forschungsrelevanter Kompetenzen. Hierbei lernen Studierende in einem standortübergreifenden Verbund der drei Hochschulen. Zentrale Module werden gemeinsam von Lehrenden aller drei Hochschulen unterrichtet. In der labortechnischen Ausbildung findet eine Einbeziehung aller Standorte statt. Bei der Spezialisierung haben Studierende Zugriff auf die volle Vielfalt der an den einzelnen Standorten verfolgten Forschungsschwerpunkte. Der Ablauf des Studiums ist dabei dreigeteilt. Das erste Fachsemester dient dem Erwerb von fachrelevanten Basiskompetenzen und der Angleichung des heterogenen Vorwissens. Das zweite und dritte Fachsemester dient der Schwerpunktbildung und Spezialisierung. Dabei werden forschungsrelevante Kompetenzen vermittelt. Das vierte Fachsemester schließt mit der Masterarbeit als eigenständiger wissenschaftlicher Leistung.

Die Vermittlung der Inhalte erfolgt in ausbalanciertem Verhältnis der drei Hochschulen. Hierbei gibt es zwei Modi der Vermittlung. Zum einen tragen in kooperativen Modulen Lehrende der drei Hochschulen in gemeinsamen Lehrveranstaltungen zu gleichen Anteilen zur Ausbildung bei. Bei den Laborpraktika erfolgt eine jährliche Rotation der Zuständigkeit bzw. auch die Einbeziehung innovativer Remote Lab Ansätze, die eigens dafür in den letzten Jahren von der MPSP entwickelt wurden und bereits einsatzbereit sind. Zum anderen tragen in den Wahlpflichtbereichen alle drei Hochschulen in gleichem Umfang belegbare Lehrveranstaltungen bei. Damit haben Studierende Zugriff auf die gesamte Expertise aller drei Standorte.

Aufbau und Gliederung des Studiums

Das Studium umfasst insgesamt 120 ECTS Credits. Hierbei werden 90 ECTS Credits in kooperativen Modulen erbracht, die in gemeinsamer Verantwortung der drei Hochschulen liegen und entsprechende Elemente in der Ausbildung der Studierenden enthalten. Hinzu kommt ein Wahlpflichtbereich, in dem Studierende frei aus den entsprechenden Angeboten der drei Universitäten auswählen und jeweilige lokale Stärken für ihre Ausbildung nutzen können.

Die kooperativen Module des ersten Fachsemesters „Introduction to Photon Science" und „IT and research methodology" werden gemeinsam von Lehrenden aller drei Hochschulen hybrid unterrichtet, während das Modul „Practical Training" als Blockpraktikum im Forschungslabor vor Ort einer Rotation der Standorte folgt. Im Wahlpflichtbereich „Adjustment" können Studierende aus dem Angebot der drei Hochschulen in enger Abstimmung mit dem zentralen MPSP Office auf sie und ihre Vorbildung zugeschnittene Veranstaltungen belegen. Das zweite und dritte Fachsemester bietet mit dem Wahlpflichtbereich „Fundamental Electives" einen weiteren Wahlpflichtbereich, in dem aus dem lokalen Angebot der Hochschulen Module der einzelnen Vertiefungsrichtungen innerhalb der Photonik belegt werden können. Von besonderem Character ist das zweisemestrige, große Modul „Specialization". Hier werden Spezialvorlesungen aus dem Angebot der drei Hochschulen als Kurse gehört, die Auswahl jedoch eng mit dem MPSP Office auf die eigenen sich entwickelnden Forschungsinteressen abgestimmt. Ein spezielles, benotetes Kolloquium am Ende des dritten Fachsemesters im Rahmen von Kommilitonen und Hochschullehrern aller drei Universitäten schließt dieses spezielle Modul ab. Im kooperativen Modul „Research Training", das ebenfalls das zweite und dritte Fachsemester andauert, werden in zwei unabhängigen Arbeitsgruppen an zwei verschiedenen Standorten praktische Forschungskompetenzen erlernt und eingeübt. Orientierung gibt ein spezielles benotetes Forschungskolloquium am Ende des ersten Projektes, das den Zwischenstand bezüglich der individuellen Forschungsmethodik erheben soll und als Planung für das zweite Projekt dienen. Das Studium wird vom Modul „Master's Thesis" im vierten Fachsemester abgeschlossen, die vor einem Gremium aus Lehrenden aller drei Hochschulen verteidigt werden muss.

Der Modulkatalog beschreibt die hier beschriebenen Module und Wahlpflichtbereiche im Detail. Für letztere sind die Modulbeschreibungen der wählbaren Module der jeweiligen Hochschulen aus den dortigen Modulkatalogen übernommen und angepasst. Die Spezialvorlesungen die innerhalb des Moduls Specialization als Kurse gehört werden können, sind ebenfalls als Übernahme aus den lokalen Modulkatalogen angehangen.

Semester	1	2	3	4	Total
Entrance and Consolidation	**Introduction** (10 ECTS) **Adjustment** (10 ECTS) **IT and Research Methodology** (5 ECTS)				25
Fundamental Electives		**Fundamental Electives** (20 ECTS)			20
Specialization		**Specialization** (20 ECTS) ⭐			20
Research Training	**Practical Training** (5 ECTS)	**Research Training** (20 ECTS) ⭐ Project 1	Project 2	**Master's Thesis** (30 ECTS)	55
ECTS	30	30	30	30	**120**

⭐ research colloquia

Modules in joint responsibility

Module Areas (Modulbereiche)

Qualifikationsziele

Ziel des Masterstudiums Photon Science and Technology ist es, die Studierenden auf eine forschungsorientierte und wissenschaftsgestützte Berufstätigkeit auf den Gebieten der Optik und Optische Technologien vorzubereiten bzw. mit der fachwissenschaftlichen Ausbildung die Basis für weiterführende Ausbildungsprogramme innerhalb oder außerhalb der Hochschule zu legen.

Die Absolventin / der Absolvent sollen sich im Studium ein vertieftes Wissen im Bereich Optik und Optische Technologien aneignen. Dies umfasst beispielsweise die Themengebiete Geometrische Optik, Wellenoptik, Elektromagnetische Theorie, Ausbreitung des Lichts, Polarisation, Interferenz, Beugung, Fourier Optik, Kohärenztheorie, Laserphysik und Integrierten Photonik. Darüber hinaus erlangen die Studierenden ein fundiertes Wissen zu Anwendungsbereichen von optischen Technologien sowohl aus physikalischer als auch aus ingenieurswissenschaftlicher Sicht. Neben diesem allgemeinen Wissen über das gesamte Themengebiet der Optik und Optischen Technologien sollen die Studierenden in gewählten Schwerpunktfächern und Praktika ein vertieftes Wissen erwerben, welches sie zu einer forschungsorientierten Fortsetzung ihrer Ausbildung befähigt. Weiterhin sollen die Studierenden im Studium die Qualifikation erwerben, ihre eigenen Forschungsarbeiten in Präsentationen und wissenschaftlichen Diskussionen auf dem Niveau der aktuellen Forschung zu präsentieren und zu diskutieren. Durch den standortübergreifenden Charakter des Studiums sollen die Studierenden die Kompetenzen erwerben, sich innerhalb einer vielfältigen Forschungslandschaft zu orientieren und zu organisieren, sowie den für die eigene Weiterentwicklung optimalen Qualifizierungspfad auszuwählen.

Zur Erlangung dieser Qualifikationsziele des gesamten Studienprogramms werden über beide Studienjahre hinweg aufbauende Qualifikationen und Kompetenzen vermittelt:

a) Im ersten Studienjahr werden unter den Leitthemen „Essentielles", „Anpassung" und „Spezialisierung" vermittelt:
- ✓ die Grundlagen des modernen Wissensstandes auf dem Gebiet der Optik und Photonik,
- ✓ die Grundlagen fortgeschrittener verwandter Themenfelder der Physik zur Vorbereitung auf die Spezialisierung,
- ✓ der aktuelle Stand der Forschung in ausgewählten Themenbereichen,
- ✓ vertiefte methodologische und methodische Kompetenzen,
- ✓ integratives Denken,
- ✓ die wesentlichen Methoden des Experimentierens in der Optik und Photonik,
- ✓ berufsfeldbezogene praktische Kenntnisse,
- ✓ konzeptionelle Kompetenzen zur Strukturierung von Forschungsfeldern, Anwendung von Theorien auf Einzelfälle und Präsentation von Ergebnissen.

b) Im zweiten Studienjahr werden unter den Leitthemen „Spezialisierung" und „Forschungsphase" vermittelt:
- ✓ vertiefte Kenntnisse in weiteren Wahlbereichen aus Teilgebieten der Optik und Photonik mit hoher Relevanz für die aktuelle Forschung,
- ✓ die Umsetzung der theoretischen, experimentellen und methodischen Grundlagen in einem themenzentrierten Forschungsprojekt,
- ✓ die Planung und Durchführung eines Forschungsprojektes,
- ✓ systematische Forschungsarbeit in einem Kollektiv,
- ✓ das Anfertigen eines wissenschaftlichen Projektberichts,
- ✓ die Präsentation von Ergebnissen und Moderation.

Nach erfolgreichem Studienabschluss verfügen die Studierenden über die fachlichen und überfachlichen Schlüsselqualifikationen (u.a. soziale Kompetenz, Teamfähigkeit), die für ein forschungsorientiertes und wissenschaftsgestütztes Berufsfeld erforderlich sind. Sie sind befähigt, fachspezifische Forschungskonzepte auszuarbeiten und umzusetzen. Dabei zeigen sie, dass sie fähig sind, wissenschaftliche Erkenntnisse kritisch einzuordnen, interdisziplinär zu denken und verantwortlich zu handeln sowie komplexe wissenschaftlich-technische Fragestellungen auch disziplinübergreifend zu analysieren und Lösungen zu erarbeiten.

Erwerb überfachlicher Kompetenzen

Das Studienangebot des Studiengangs ist auf einen expliziten Erwerb unterschiedlicher Kompetenzen hin ausgerichtet. Das für alle Studierende verpflichtende Modul „IT and Research Methodology" führt explizit in Methoden wissenschaftlichen Arbeitens ein. Es beinhaltet insbesondere:

- ✓ Standardschritte wissenschaftlicher Arbeit
- ✓ Qualitätskriterien für gute wissenschaftliche Arbeit
- ✓ Forschungsdatenmanagement
- ✓ Software für wissenschaftliche Praxis (Zitiersoftware, etc)
- ✓ Laborautomation
- ✓ Programmiertechniken
- ✓ Kompetenzerwerb Selbstlernen mit Online-Angeboten

Das Modul „Pratical Training" vertieft neben fachlichen Aspekten vor allem auch die Kompetenzen im Bereich Labormanagment und -automation. Eine Besonderheit ist hier die Ableistung an zwei Standorten. So werden Schwerpunkte und Spezifika beider Standorte erfahrbar gemacht.

In den Modulen "Research Training" und „Master's Thesis" erfolgt eine intensive, forschungsbezogene Tätigkeit. Dabei werden alle Kompetenzen aus dem Bereich der wissenschaftlichen Arbeit weiter trainiert und vertieft. Ein großes Augenmerk liegt auf der Einhaltung der Kriterien für gute wissenschaftliche Arbeit. Weiter wird das Verfassen wissenschaftlicher Berichte und Abhandlungen intensiv geübt.

In den Modulen „Specilisation", „Research Training" und „Master's Thesis" sind umfangreiche Präsentationen verpflichtend. Zur systematischen Vorbereitung darauf, wird in den obligatorischen Spring und Autumn Schools entsprechende Trainingsangebote gemacht.

Die Teilnahme an Lehrveranstaltungen von Dozenten/innen verschiedener Studienorte bzw. von Lehrveranstaltungen in gemeinsamer Verantwortung lernen die Studierenden aus unterschiedlichen Traditionen und Schwerpunktsetzungen resultierende Perspektiven kennen, was zu einer deutlichen Stärkung der Fähigkeit zur Perspektivenübernahme und der kognitiven Flexibilität beiträgt. In den Praktika, die an verschiedenen Studienorten abzuleisten sind, wird somit die Interaktion mit verschiedenen Akteuren und wissenschaftlichen Kulturen vertieft eingeübt.

Naturgemäß unterstützt ein internationaler Studiengang interkulturelle Begegnungen in verschiedenster Weise Die interkulturellen Aspekte werden in kontinuierlicher Studienberatung und Reflexionsangeboten in Spring und Autum Schools begleitet und aufgearbeitet.

Die Arbeit an verschiedenen Studienstandorten fördert und bildet die Fähigkeit zum selbständigen und situationsadaptierten Arbeiten und zur Selbstorganisation.

In Spring School und Autumn School werden durch externe Dozenten/innen wichtige Schlüsselqualifikationen (Selbstmanagment, Kommunikation, etc.) vermittelt. Durch Dozenten/innen aus der Industrie wird die Orientierung im diesem später möglichen Arbeitsumfeld erleichtert.

Verhältnis der Qualifikationsziele auf Studiengangs- und Modulebene

Das zentrale Qualifikationsziel ist die Kompetenz zu selbständiger wissenschaftlicher Arbeit im Bereich Photonik auf hohem internationalen Niveau. Diese Kompetenz setzt sehr gut entwickelte theoretische und methodische Kenntnisse sowie deren Einübung durch Umsetzung in tatsächlichen Forschungsaktivitäten voraus.

Die Module bauen strukturiert aufeinander aufeinander auf. Im ersten Semester werden durch die Module „Introduction to Photon Science", „Adjustment", „IT and Research Methodology" und „Practical Training" die entscheidenden theoretischen und methodischen Grundlagen gelegt. Das explizite Modul „IT and Research Methodology" stellt dabei sicher, dass diese wichtigen Querschnittqualifikationen explizit und reflektiert erworben werden.

Die im ersten Semester gelegten Grundlagen werden in den Modulen „Fundamental Elective" und „Specialization" vertieft. Diese greifen auf die Grundlagen zurück, vertiefen ausgewählte Inhaltsbereiche und bereiten auf die „Master's Thesis" vor. Das parallel absolvierte Modul „Research Training" sorgt im speziellen für eine Schnittstelle zur abschließenden „Master's Thesis", da es die theoretische Vertiefung bereits parallel in angewandte Forschungsaktivität umsetzt. Eine kontinuierliche Studienberatung sorgt für eine in sich stimmige Kombination aus Kursen / Forschungsprojekten im zweiten und dritten Semester, die zudem sinnvoll auf eine anschließende „Master's Thesis" bezogen ist.

Die abschließende „Master's Thesis" führt alle vorher erworbenen Kompetenzen zusammen.

Durch die kontinuierliche Studienberatung, aber speziell auch durch die Spring School und Autumn School wird der Kompetenzerwerb kontinuierlich reflektiert und so gefestigt bzw. im Bedarfsfall adjustiert.

Inhalt

Core Modules

Module Introduction to Photon Science

Modulcode	IN
Modultitel (deutsch)	Einführung in die Photonik
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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	winter semester
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 (einschl. Prüfungsvorbereitungen)	210 h
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.
Prerequisites for assessment	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.
Unterrichtssprache	English
Additional information on the module *	Educators from all three universities offer the course in equal parts including lectures and seminars. All partners agree upon a joint course program with balanced individual contributions. This course program includes contents for lectures, exercises and examinations. In practice, this is realized by splitting the course into three equal parts that are each attributed to an educator from each location. Each part is taught online to the entire cohort of students. The responsibility for the primary organization is rotated annually among the three universities.

Module Area Adjustment	
Modulcode	AD
Modultitel (deutsch)	Anpassung
Modultitel (englisch)	Adjustment
Modul-Verantwortliche/r	N/A
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Compulsory Module Area
Häufigkeit des Angebots (Modulturnus)	N/A
Dauer des Moduls	1 semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	
Leistungspunkte (ECTS credits)	10 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	300 h
Inhalte	The students select courses depending on their individual educational background upon a recommendation from the study coordination office. They must achieve at least 10 ECTS credits to successfully complete the module area. We list here individual modules, which can be taken to successfully complete this module area. It is possible to acknowledge further modules upon decision of the study commission. • Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics (FAU) • Advanced Theoretical Physics (FAU) • Structure of Matter (FSU) • Condensed Matter Theory I, Fundamentals (KIT) • Measurement and Control Systems (KIT)

	• Modern Physics (KIT)
Lern- und Qualifikationsziele	The expected learning outcomes of the Adjustment module are: • for students with a background in natural sciences, to elaborate their fundamental knowledge in systems theory, information acquisition and measurement, as well as in computational concepts and methods. • for students with a background in engineering sciences, to elaborate their knowledge in basic modern physics, including the fundamentals applications of quantum physics and how to solve physics problems by mathematical evaluation of natural laws.
Prerequisites for assessment	As defined for the individual modules
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Successful completion of 10 ECTS credits in total. Grading: The final grade of the module area is the average from all creditable examination results weighted by the respective ECTS credits.
Unterrichtssprache	English
Additional information on the module *	

Module IT and Research Methodology

Modulcode	IT
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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	winter semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	This module conveys competence in using information technology and resources. The course captures the following aspects: • Programming skills in a generic and ubiquitously used language such as Python or C++. • Essential aspects of lab-automation to mirror the needs of a solid education to information aspects not just in theoretical and numerical science but also in experimental science. • Outlining the most important aspects of online learning and, in perspective, also teaching, the use of AI etc. • Introduction to Good Scientific Practice. • Research Data Management.

	• The use of tools to work in the scientific world, particularly in a partially online environment.
Lern- und Qualifikationsziele	Students completing the IT and Research Methodology module should be able to evaluate and to use the basic general methods, which are essential to conduct research in an academic environment. • Besides enabling efficient research, the module should also provide the ground for quality control in research and create awareness of the limits of good scientific practice.
Prerequisites for assessment	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 120mins) or oral examination (30, 45, or 60mins) Grading: from examination result.
Unterrichtssprache	English
Additional information on the module *	Educators from all three teaching universities offer the course in equal parts including lectures and seminars. All partners agree upon a joint course program with balanced individual contributions. This course program includes contents for lectures and seminars as well as exercises and examinations. In practice, this could be realized by splitting the course in three equal parts that are each attributed to an educator from each location. Each part is taught online to the entire cohort of students. If necessary, one of the three teaching universities takes primary responsibility while the other partners support the module in equal parts. The responsibilities for the individual teaching universities along with any additional teaching load are limited by virtue of an annual rotation.

Module Practical Training

Modulcode	PT
Modultitel (deutsch)	Praktische Ausbildung
Modultitel (englisch)	Practical Training
Modul-Verantwortliche/r	S. Nolte (FSU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	winter semester
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 (einschl. Prüfungsvorbereitungen)	120 h
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.
Prerequisites for assessment	6 experimentation sessions with a duration of 5 hours must be

	completed. Students submit a written report for each experiment and receive a feedback in the form: good (+), sufficient (o), or insufficient (-) for each individual experiment. Experiments with an insufficient outcome must be done again or replaced by a different experiment.
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: - Grading: pass / no pass
Unterrichtssprache	English
Additional information on the module *	The teaching universities organize the course at one of the three locations. All students of the Collaborative Master's program participate in it together. The course takes place after the examination period of the first semester has ended. In this optics and photonics lab course, the students choose according to their interests among multiple optics experiments that are offered. In groups of two or three, students carry out experiments according to their preferences. The composition of the groups changes with each rotation. Educators from all three teaching universities offer the course in equal parts. All partners agree upon a joint course program with balanced individual contributions. This course program includes access to and supervision of optical training experiments and numerical experiments. The majority of basic training experiments is available at all three sites allowing for consistent education across cohorts. If necessary, one of the three teaching universities takes primary responsibility while the other partners support the module in equal parts. The responsibilities for the individual teaching universities along with any additional teaching load are limited by virtue of an annual rotation.

Module Area Fundamental Electives	
Modulcode	FE
Modultitel (deutsch)	Grundlegende Wahlfächer
Modultitel (englisch)	Fundamental Electives
Modul-Verantwortliche/r	N/A
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Compulsory module area
Häufigkeit des Angebots (Modulturnus)	
Dauer des Moduls	2 semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lectures and exercises
Leistungspunkte (ECTS credits)	20 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	600 h
Inhalte	The students select courses depending on their individual interest to lay foundations for a research direction within Photonics. They must achieve at least 20 ECTS credits to successfully complete the module area. We list here individual modules, which can be taken to successfully complete this module area. It is possible to acknowledge further modules upon decision of the study commission. • Advanced Optical Communication Systems (FAU, 5 ECTS) • Modern Optics 3: Quantum Optics (FAU, 5 ECTS) • Computational Optics (FAU, 5 ECTS) • Waveguides, Optical Fibres and Photonic Crystal Fibres (FAU, 5 ECTS)

	• Introduction to Optical Modelling (FSU, 5 ECTS) • Laser Physics (FSU, 10 ECTS) • Optical Metrology and Sensing (FSU, 5 ECTS) • Laser Physics (KIT, 5 ECTS) • Nano-Optics (KIT, 10 ECTS) • Nonlinear Optics (KIT, 5 ECTS) • Optoelectronic Components (KIT, 5 ECTS) • Solid-State Optics (KIT, 10 ECTS) • Theoretical Optics (KIT, 5 ECTS) The modules are offered by the individual universities. Further information can be found in the entries of the respective module catalogue below.
Lern- und Qualifikationsziele	The students learn about fundamentals and methods of principal research directions in photonics which includes experimental techniques as well as theoretical and computational aspects. The students will be familiarized with important applications of fundamental photonics effects.
Prerequisites for assessment	As defined for the individual modules
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Successful completion of 20 ECTS credits in total. Grading: The final grade of the module area is the average from all creditable examination results weighted by the respective ECTS credits.
Unterrichtssprache	English
Additional information on the module *	

Module Specialization	
Modulcode	SP
Modultitel (deutsch)	Spezialisation
Modultitel (englisch)	Specialization
Modul-Verantwortliche/r	I. Staude (FSU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	every semester
Dauer des Moduls	2 semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lectures, exercises and seminar
Leistungspunkte (ECTS credits)	20 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	600 h
Inhalte	The module consists of two parts. In the first part, the students select courses depending on their individual interest to acquire specialized knowledge in Photonics. They must successfully complete courses with a workload equivalent to at least 20 ECTS credits. In the second part, students have to successfully complete a presentation at the end of the third semester. This consists of a poster presentation seminar at the MPSP Spring School about the individual specialization path and projects. We list individual courses, which can be taken to successfully complete this module in the appendix. It is possible to acknowledge further courses upon decision of the module coordinator.

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

	quantum optical phenomena, the necessary theoretical means for their description, and the application of quantum optical resources in different applications and technologies. They learn how to express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum optical phenomena in specific situations. The course provides training to solve basic problems in quantum optics.
Prerequisites for assessment	According to the individual courses
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Successful completion of courses equivalent to a workload of 20 ECTS credits and passing of module examination. Type of Examination: EITHER volunteering to take the individually offered course examinations OR taking an overarching examination (written, 180mins) at the end of the 3rd semester. The presentation is judged by an advisory committee. The committee consists of three educators of each teaching university. During the module examination, the student discusses lecture contents and project results with the committee. The presentation is graded as "passed" or "not passed". Grading: EITHER the average of all creditable voluntary examination results weighted by the respective workload of the courses (ECTS equivalent) OR the result of the overarching examination.
Unterrichtssprache	English
Additional information on the module *	

Module Research Training	
Modulcode	RT
Modultitel (deutsch)	Research Training
Modultitel (englisch)	Research Training
Modul-Verantwortliche/r	C. Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	every semester
Dauer des Moduls	2 semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Practical labwork and seminar.
Leistungspunkte (ECTS credits)	20 LP
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	600 h
Inhalte	The student chooses two research projects in two different research groups in the 2nd and 3rd semester. Depending on the topic the total workload of 300h per project should be distributed approximately as: • 50 h introduction to the research topic (study of relevant literature, ...) • 190 h research work (in the lab for experimental topics or theoretically / numerically) • 50 h preparation of the final report • 10 h preparation and carrying out presentation of the results 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.
	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.
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.
Prerequisites for assessment	Written report on first research project and presentation of second research project
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: Seminar presentation of first research project and written report on second presentation Grading: Average of the grades for the presentation and the written report.
Unterrichtssprache	English
Additional information on the module *	The students are working on research projects in different labs.

Module Master's Thesis	
Modulcode	MT
Modultitel (deutsch)	Masterarbeit
Modultitel (englisch)	Master's Thesis
Modul-Verantwortliche/r	N. Joly (FAU), I. Staude (FSU), C. Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: compulsory
Häufigkeit des Angebots (Modulturnus)	every semester
Dauer des Moduls	1 semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Practical course. total workload: 900 h depending on the topic this total workload should be distributed approximately as: • 225 h introduction to the research topic (study of relevant literature, ...) • 450 h research work (in the lab for experimental topics and at computer etc. for theoretical topics) • 200 h preparation of the final report • 25 h preparation and carrying out presentation of the results
Leistungspunkte (ECTS credits)	30 LP
Arbeitsaufwand (work load) in: - Präsenzstunden	900 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	900 h
Inhalte	The research towards the thesis will be performed in a research group, in an industrial research lab or a research institution. The topic of the thesis must be related to the area of optics and photonics and will be assigned, supervised, and refereed by a thesis advisory committee. Three educators/representatives from each location form a thesis

	advisory committee.
	Committee meetings with the student take place at the beginning of the thesis work and shortly before finalizing of the thesis research work.
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 thesis.
	Ideally, this scientific work is the basis for a continuation of the student's academic progress by transitioning to the MPSP research phase (PhD project).
Prerequisites for assessment	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
Unterrichtssprache	English
Additional information on the module *	A thesis advisory committee closely supervises the research towards the thesis. In this way, educators from all three teaching universities are involved in the supervision in equal parts. Significant weight is on the partial grade related to the interaction of the student with the committee to emphasize the special importance of the unique cross-locational joint supervision

Module

aus den jeweiligen Modulhandbüchern für den

Wahlpflichtbereich

Adjustment

Modul 42155 Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics

Modulcode	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)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Only in winter semester
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 (einschl. Prüfungsvorbereitungen)	210 h
Inhalte	Introduction: Fundamental Properties and working scheme of the Laser, applications Optical resonators: Ray transfer matrix analysis, stability criteria for optical resonators Propagation of waves in optical media: Solutions to the wave equation, complex index of refraction, dispersion Gaussian beams: Solution of the paraxial wave equation, Gaussian beams of higher order, properties of Gaussian beams, Gaussian beams and resonators, resonators as interferometer and spectrometer

| | Light-matter interaction:
Classical description, semiclassical description, stimulated emission, black body radiation, interaction of a two-level atom with a monochromatic wave
Theory of the laser:
Maxwell-Bloch-equations, laser operation in equilibrium, rate equations, outcoupled laser power, relaxation oscillations, micro-lasers, laser noise (Schawlow- Townes-Limit), generation and measurement of ultrashort pulses
Laser systems:
Gas lasers, solid state lasers, vibronic lasers, laser frequency analysis and stabilization
Laser spectroscopy:
Spectral lines + -profiles, broadening mechanisms, doppler-free spectroscopy
Cooling and trapping of atoms:
Doppler cooling, magneto-otical trap, trapping of single atoms, Bose-Einstein-condensation |
|---|---|
| Lern- und Qualifikationsziele | Students

 • explain and analyze advanced topics of lasers, atomic physics and quantum optics as outlined in the table of contents
 • apply the associated physical concepts to specific problems using appropriate methods |
| Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform) | Written examination (100%) |
| Unterrichtssprache | english |

Modul 66961 Advanced theoretical physics

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Every 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 (einschl. Prüfungsvorbereitungen)	195 h
Inhalte	**Course Advanced Quantum Mechanics (TV-A):** The course covers an introduction to quantum field theory. The following main topics will be discussed in the lecture: • Motivation Quantum Field Theory

• Classical Field Theory (Hamiltonian, Lagrange formalism for classical field theories)

• Relativistic Quantum Mechanics (Klein-Gordon and Dirac equation)

• Representation Theory Lorentz- und Poincare-Groups (finite dimensional scalar-, vector, tensor and spinor representations of the Lorentz group, infinite dimensional representations: field representations, finite and infinite dimensional representation of the Poincare group)

• Quantisation of Free Fields (multi particle states, Fock space, canonical quantisation of scalar, vector and spinor fields)

• Quantisation of Interacting Field Theories (interaction picture, Dyson series, perturbation theory, S-matrix, Feynman rules, Higgs Mechanism)

Course Advanced Solid State Physics (TV-B):

The following main topics will be discussed in this course:

• Structure of solids: Bravais lattices, reciprocal lattice, Brillouin zone

• The solid as a many-body problem: Hamiltonian of a solid, electron-electron interaction, electron-ion interaction, separation of electronic and ionic motion (Born-Oppenheimer approximation), types of bonding

• Lattice dynamics: Phonons: Harmonic approximation, classical solution, dispersion relation, acoustic and optical modes, Debye and Einstein model, quantum theory of lattice vibrations, phonons, density of states, van Hove singularities, hermal properties, anharmonic effects

• Electrons in a periodic potential: Bloch theorem, band structure, nearly free electrons, tight-binding method, Wannier functions, metals, insulators, semiconductors, density of states, Fermi surface, quantum statistics, thermal properties, Fermi distribution

• Electron-electron interaction: Hartree-Fock method, density functional theory, homogeneous electron gas

• Topics of current research

Lern- und Qualifikationsziele	**Course Advanced Quantum Mechanics (TV-A):** Students • comprehend, outline and explain classical and quantum field theory, as well as relativistic quantum mechanics • apply the methods of advanced quantum mechanics to specific problems **Course Advanced Solid State Physics (TV-B):** Students • comprehend, outline and explain the theory of structure and many-body properties of solids, phonons, electrons in a periodic potential and their interaction as well as transport theory

	• apply the methods of advanced theoretical solid-state physics to specific problems
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written examination (100%)
Empfohlene Literatur	no Bibliography information available!
Unterrichtssprache	english

Modul PAFMO002 Structure of Matter

Modulcode	PAFMO002
Modultitel (deutsch)	Structure of Matter
Modultitel (englisch)	Structure of Matter
Modul-Verantwortliche/r	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Voraussetzung für die Zulassung zum Modul	None
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	210 h
Inhalte	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	The students - understand the classical interaction of light with matter and basic quantum mechanics - can apply Einstein coefficients, Planck's formula, and selection rules - have a solid understanding of the hydrogen and helium atoms - can analyze molecular spectroscopy data and optical properties of materials

	- understand the dielectric function, Kramers-Kronig relations, and basic nonlinear optical effects
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 ElectrodynamicsE. Hecht, "Optics"
Unterrichtssprache	English

4.43 Modul Condensed Matter Theory I, Fundamentals [M-PHYS-102054]

Modulcode	4.43 Modul M-PHYS-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)
Voraussetzung für die Zulassung zum Modul	none
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	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: • 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	• 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	English

2.33 Modul: Measurement and Control Systems [M-MACH-101921]

Modulcode	2.33. Modul M-MACH-101921
Modultitel (deutsch)	Measurement and Control Systems
Modultitel (englisch)	Measurement and Control Systems
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christoph Stiller (KIT)
Voraussetzung für die Zulassung zum Modul	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	105 h
Inhalte	I. Dynamic systems
	II. Properties of important systems and modeling
	III. Transfer characteristics and stability
	IV. State-space description
	V. Controller design
	VI. Fundamentals of measurement
	VII. Estimation
	VIII. Sensors
	IX. Introduction to digital measurement
	Learning type: Lecture and excercise
Lern- und Qualifikationsziele	The students

	• possess knowledge in the theory of linear time-invariant systems in time domain, state space, and frequency domain • canformulateasystemmodelforpracticaldevices • 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	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
Unterrichtssprache	English

2.34 Modul Modern Physics [M-PHYS-101931]

Modulcode	M-PHYS-101931
Modultitel (deutsch)	Modern Physics
Modultitel (englisch)	Modern Physics
Modul-Verantwortliche/r	apl. Prof. Dr. Bernd Pilawa (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Adjustment
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	105 h
Inhalte	I. Introduction II. Electromagnetism III. Special Relativity IV. Quantum mechanics V. Atoms VI. Solids
Lern- und Qualifikationsziele	The students from different backgrounds refresh and elaborate their knowledge of basic physics. They comprehend the fundamentals of quantum physics and their application to atoms, nuclei and particles. They learn how to describe physical laws in a mathematical form and how to solve problems in modern physics by mathematical evaluation of these physical laws. Learning targets

	The students • are familiar with the basic experimental results leading to Maxwell's equations • know how to apply Maxwell's equations to simple problems in electromagnetism • conceive the relation between relativity and electromagnetism • comprehend the coherence of the particle and wave description of light and matter • understand the basic principles leading to the Schrödinger-equation • are able to apply the Schrödinger-equation to basic problems in quantum mechanics • comprehend the limits of wave mechanics • have a good understanding of atoms with many electrons •know the fundamental properties of solids and especially the properties of electrons in crystalline solids.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Paul A. Tipler: Physics for engineers and scientists Paul A. Tipler: Modern Physics
Unterrichtssprache	Englisch

Module

aus den jeweiligen Modulhandbüchern für den

Wahlpflichtbereich

Fundamental Electives

Modul 621649 Advanced Optical Communication Systems

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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	Students
	• gain detailed Knowledge on concepts and structure of various optical transmission systems.
	• are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts.
	• are able to develop and to optimize link designes of optical transmission systems.
	• are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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 48313 Modern Optics 3: Quantum Optics

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every 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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	Contents: 1. Basic concepts of statistical optics 2. Spatial and temporal coherence. Coherent modes, photon number per mode 3. Intensity fluctuations and Hanbury Brown and Twiss experiment 4. Interaction between atom and light (semiclassical description) 5. Quantization of the electromagnetic field 6. Quantum operators and quantum states 7. Heisenberg and Schrödinger pictures 8. Polarization in quantum optics 9. Nonlinear optical effects for producing nonclassical light 10. Parametric down-conversion and four-wave mixing, biphotons, squeezed light

	11. Single-photon states and single-photon emitters
	12. Entanglement and Bells inequality violation
Lern- und Qualifikationsziele	Learning goals and competences:
	Students
	• 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 43220 Computational Optics

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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	students will be able to: 1. **Explain the fundamental principles** underlying the simulation of optical wave phenomena and their relevance in modern photonics. 2. **Apply the finite-difference method** to numerically solve Maxwell's equations in the context of optical wave propagation. 3. **Utilize beam propagation methods (BPM)** to model and analyze guided-wave and free-space optical systems. 4. **Formulate and solve photon rate equations** for the simulation of light–matter interaction in optoelectronic devices.

	5. **Develop and implement computational models** for simulating the performance of lasers and thin-film solar cells. 6. **Critically assess simulation results** and validate them against physical models and empirical data.
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 67145 Waveguides, optical fibres and photonic crystal fibres

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	90 h
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 - 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 PAFMO004 Laser Physics

Modulcode	PAFMO004
Modultitel (deutsch)	Laser Physics
Modultitel (englisch)	Laser Physics
Modul-Verantwortliche/r	Prof. Dr. J. Limpert (FSU), Prof. Dr. S. Nolte (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives (Required elective Module M.Sc. Physics focus „Optics"Compulsory Module M.Sc. Photonics)
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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:	300 h
- Präsenzstunden	90 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	210 h
Inhalte	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	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

Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives (628 M.Sc. Photonics: compulsory module128 MSc. Physics: required elective module)
Häufigkeit des Angebots (Modulturnus)	Every winter term
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 (einschl. Prüfungsvorbereitungen)	100 h
Inhalte	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	The students understand the basic principles and wave optical fundamentals of optical metrology are familiar with key sensor technologies and measurement techniques can apply interferometry, holography, and speckle methods for precise measurements understand phase retrieval and its role in optical metrology can analyze and compare metrology techniques for aspheres, freeform surfaces, and confocal methods

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 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
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives (628 M.Sc. Photonics: compulsory module128 MSc. Physics: required elective module)
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	100 h
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 aims to show how linear optics is applied for modeling and design of optical elements and systems. In the first part of the lecture we focus on ray-tracing techniques and its application through image formation. Then we combine the concepts with physical optics and obtain field tracing. It enables the propagation of vectorial harmonic fields through optical systems. In practical exercises the students will get an introduction to the use of commercial optics modeling and design software.

Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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

2.29 Modul Laser Physics [M-ETIT-100435]

Modulcode	M-ETIT-100435
Modultitel (deutsch)	Laser Physics
Modultitel (englisch)	Laser Physics
Modul-Verantwortliche/r	Prof. Dr. Marc Eichhorn (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	95 h
Inhalte	Within the module the physical basics of lasers, the fundamental processes of light amplification and the formalisms necessary to describe lasers and laser resonators are covered. The generation of laser pulses and various laser architectures as well as realisations are presented in detail.
	The exercises specifically discuss the topics of laser description, theoretical background as well as the realization of different laser designs. The tasks of the exercise will be handed out at the end of each lecture as well as uploaded to the lecture website and are to be solved for the following exercise, in which the solution will be discussed.
	Contents:
	1 Quantum-mechanical fundamentals of lasers
	1.1 Einstein relations and Planck´s law
	1.2 Transition probabilities and matrix elements

	1.3 Mode structure of space and the origin of spontaneous emission
	1.4 Cross sections and broadening of spectral lines
	2 The laser principles
	2.1 Population in version and feedback
	2.2 Spectroscopic laser rate equations
	2.3 Potential model of the laser
	3 Optical Resonators
	3.1 Linear resonators and stability criterion
	3.2 Mode structure and intensity distribution
	3.3 Line width of the laser emission
	4 Generation of short and ultra-short pulses
	4.1 Basics of Q-switching
	4.2 Basics of mode locking and ultra-short pulses
	5 Laser examples and their applications
	5.1 Gas lasers: The Helium-Neon-Laser
	5.2 Solid-state lasers
	5.2.1 The Nd^{3+}-Laser
	5.2.2 The Tm^{3+}-Laser
	5.2.3 The $Ti^{3+}:Al_2O_3$ Laser
	5.3 Special realisations of lasers
	5.3.1 Thermal lensing and thermal stress
	5.3.2 The fiber laser
	5.3.3 The thin-dis laser
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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)

Unterrichtssprache	Englisch

2.37 Modul Nano-Optics [M-PHYS-102146]

Modulcode	M-PHYS-102146
Modultitel (deutsch)	Nano-Optics
Modultitel (englisch)	Nano-Optics
Modul-Verantwortliche/r	Dr. Andreas Naber (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	210 h
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 • 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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

2.38 Modul Nonlinear Optics [M-ETIT-100430]

Modulcode	M-ETIT-100430
Modultitel (deutsch)	Non-linear Optics
Modultitel (englisch)	Non-linear Optics
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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	The students

	• understand and can mathematically describe the effect of basic nonlinear- optical phenomena using optical susceptibility tensors,
	• understand and can mathematically describe wave propagation in nonlinear anisotropic materials,
	• have an overview and can quantitatively describe common second-order nonlinear effects comprising the electro-optic effect, second-harmonic generation, sum- and difference frequency generation, parametric amplification and optical rectification,
	• have an overview and can quantitatively describe the Kerr effect and other common third-order nonlinear effects, comprising self- and cross-phase modulation, four-wave mixing, self-focussing, and third-harmonic generation,
	• have an overview and can describe nonlinear-optical interaction in active devices such as semiconductor optical amplifiers
	• conceive the basic principles of various phase-matching techniques and can apply them to practical design problems,
	• conceive the basic principles electro-optic modulators, can apply them to practical design problems, and have an overview on state-of-the art devices,
	• conceive the basic principles third-order nonlinear signal processing and can apply them to practical design problems.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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.
Unterrichtssprache	Englisch

2.46 Modul Optoelectronic Components [M-ETIT-100509]

Modulcode	M-ETIT-100509
Modultitel (deutsch)	Optoelectronic Components
Modultitel (englisch)	Optoelectronic Components
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	100 h
Inhalte	The course concentrates on the most basic optical communication components. Emphasis is on physical understanding, exploiting results from electromagnetic field theory, (light waveguides), solid-state physics (laser diodes, LED, and photodiodes), and communication theory (receivers, noise). The following components are discussed: • Light wave guides: Wave propagation, slab. wave guides, strip wave guides, integrated optical wave guides, fibre waveguides • Light sources and amplifiers: Luminescence and laser radiation, luminescent diodes, laser diodes, stationary and dynamic behavior, semiconductor optical amplifiers • Receivers: pin photo diodes, electronic amplifiers, noise
Lern- und Qualifikationsziele	Comprehending the physical layer of optical communication systems. Developing a basic understanding which enables a designer to read a device´s data sheet, to make most of its properties, and to avoid hitting its limitations. The students

	• understand the components of the physical layer of optical communication systems
	• acquire the knowledge of operation principles and impairments of optical wave guides
	• know the basics of laser diodes, luminescence diodes and semiconductor optical amplifiers
	• understand pin-photodiodes
	• know the systems´ sensitivity limits, which are caused by optical and electrical noise
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	-
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

2.57 Modul Solid-State Optics [M-PHYS-102408]

Modulcode	M-PHYS-102408
Modultitel (deutsch)	Solid-State Optics
Modultitel (englisch)	Solid-State Optics
Modul-Verantwortliche/r	PD Dr. Michael Hetterich (KIT) Prof. Dr. Heinz Kalt (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	210 h
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	• 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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	H.Kalt,C.Klingshirn:SemiconductorOptics F.Wooten:OpticalPropertiesofSolids P.K.Basu:Theoryofopticalprocessesinsemiconductors H.IbachandH.Lüth:Solid-StatePhysics
Unterrichtssprache	Englisch

2.61 Modul Theoretical Optics [M-PHYS-102280]

Modulcode	M-PHYS-102280
Modultitel (deutsch)	Theoretical Optics
Modultitel (englisch)	Theoretical Optics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Module Fundamental Electives
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	100 h
Inhalte	- 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	The students deepen their knowledge about the theory and the mathematical tools in optics and photonics. They learn how to apply these tools to describe fundamental phenomena and how to predict observable quantities that reflect the actual physics from the theory by way of a corresponding purposeful mathematical analyses. They learn how to solve problems of both, interpretative and predictive nature with regards to model systems and real life situations.
	The students
	• understand the theoretical basis and physical content of the classical Maxwell equations and the quantum description of light
	• know how to formulate and discuss optical properties in mathematical form
	• are able to utilize advanced mathematical tools for the quantitative description of wave propagation in various settings such as anisotropic materials and diffractive systems
	• are able to quantify and utilize basic phenomena of coherence
	• are familiar with the quantitative analysis of classical wave propagation in basic devices and systems
	• appreciate the limitations of the classical description of light and the novel phenomena as sociated with systems for which a quantum description is required
	• are able to quantitatively analyse simple quantum optical devices
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	• "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

Kurse

aus den jeweiligen Modulhandbüchern für das Modul

Specialization

Modul 67112 Advanced microscopic techniques

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	In this course we will cover the following topics: 1. 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. 2. 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. 3. 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
	4. 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.
	5. 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.
	6. 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.
	7. 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.
	8. Polarization sensitive optical coherence tomography (ps-OCT): ps-OCT is gaining attention because of its ability to diagnose certain pathological conditions at an early stage. Several pathological conditions such as cancer can be detected at an early stage by measuring birefringent properties of the tissue. ps-OCT uses low coherence polarized light to probe the birerefregence of the tissue.
	9. 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 • 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 582360 Modern Optics 2: Nonlinear Optics

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	*Contents:* • 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	The students - understand linear and nonlinear optical properties of materials - can explain the origin of nonlinear susceptibility and the role of phase-matching - are able to derive and analyze coupled equations for second harmonic generation understand electro-optic effects and third-order nonlinearities - can describe modulation instability, soliton dynamics, and supercontinuum generation - are familiar with nonlinear optical processes in photonic crystal fibers and their applications
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	*Literature:* 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 67009 Novel techniques in ultrafast spectroscopy

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	Review of recently developed techniques for the characterization of the dynamical response of complex materials:
	1) Single and multipartite dynamics in non-linear spectroscopy
	https://www.nature.com/articles/s41586-023-05846-7
	2) Two dimensional optical spectroscopy
	https://onlinelibrary.wiley.com/doi/full/10.1002/andp.201300153
	3) Two dimensional broadband electronic spectroscopy
	https://pubs.acs.org/doi/abs/10.1021/acs.chemrev.1c00623
	4) Driving complex matter with mid-IR pulses Phonon pump
	https://www.nature.com/articles/nphys2055
	5) Ultrafast x-ray probes of dynamics in solids
	https://arxiv.org/abs/2108.05456

	6) Ultrafast electron probe of dynamics in solid
	https://www.science.org/doi/10.1126/science.1090052
	7) Ultrafast X-ray imaging of the light-induced phase transition in VO2
	https://www.nature.com/articles/s41567-022-01848-w
	8) Subcycle contact-free nanoscopy of ultrafast interlayer transport in atomically thin heterostructures https://www.nature.com/articles/s41566-021-00813-y
	9) The role of phonons in ultrafast demagnetization https://www.nature.com/articles/s41586-021-04306-4
	10) New experimental approaches to two-dimensional electronic spectroscopy https://pubs.aip.org/aip/rsi/article/85/12/123107/109430/
Lern- und Qualifikationsziele	Students • comprehend an interesting physical topic in a short time frame • identify and interpret the appropriate literature • select and organize the relevant information for the presentation • compose a presentation on the topic at the appropriate level for the audience • give a presentation to a scientific audience and use the appropriate presentation techniques and tools • criticize and defend the topic in a scientific discussion
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 42935 Optical diagnostic in energy and process engineering

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every winter 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	Introduction to conventional and novel optical techniques to measure state and process functions in thermodynamical systems: • Properties of light; properties of molecules; Boltzmann distribution • Geometric optics and optical devices • Lasers (HeNe, Nd:YAG, dye, frequency conversion); continuous wave and pulsed lasers • Photoelectric effect; photodetectors (photomultiplier, photodiode, CCD, CMOS, image intensifier); digital image processing; image noise and resolution • Shadowgraphy and Schlieren techniques (flow and mixing)

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• 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)

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<td>Lern- und Qualifikationsziele</td>
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Students gain technical and technological skills in the field of optical techniques for the measurement of state and process variables in thermodynamic / energy processes and the investigation of these processes. They

• are familiar with the state of the art and latest developments in optical measurement techniques applied in thermodynamics / energy processes

• can assess the applicability of measurement techniques in different environments

• can apply different optical measurement techniques in thermodynamic processes and design experiments

• can evaluate data gained from optical measurement techniques and assess the quality of data

• know interdisciplinary approaches in the fields of optics, thermodynamics, heat and mass transfer and fluid mechanics

• are qualified to perform applied and fundamental research and development tasks in industry and at university in the field of optical measurement techniques for thermodynamic / energy processes

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<td>Voraussetzung für die Zulassung zur Modulprüfung</td>
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<td>Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)</td>
<td>30 min oral exam</td>
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<td>Zusätzliche Informationen zum Modul</td>
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<td>Empfohlene Literatur</td>
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Lecture Slides

Bräuer, Andreas: In situ Spectroscopic Techniques at High Pressure, Amsterdam 2015

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<td>Unterrichtssprache</td>
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Modul 45730 Optical Technologies in Life Science

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	Content • Application of optical methods in the field of cell biology and medicine • Microscopy: Basic concepts, methods to enhance contrast, optical resolution and limits, components and setup of light microscopes, fluorescence microscopy • Applications of fluorescence microscopy in life sciences, methods for labeling of biological structures and cellular processes´ • Epi-fluorescence, confocal and multiphoton microscopy, concepts and application examples • Optical endoscopy and endomicroscopy in research and clinics • Super-resolution microscopy, concepts and applications for optical Imaging beyond the diffraction Limit of Resolution
Lern- und Qualifikationsziele	Students

	• understand the basic concepts and specific technical approaches to optical technologies in life sciences and identify typical applications examples. • can analyze and compare different technical approaches to scientific research questions. • can summarize advantages and disadvantages of different technologies and assess theoretical and practical limitations with regard to experimental approaches and results. • can find, collect and structure in-depth information on technical solutions, materials and methods in the areas of microscopy and spectroscopy, in order to plan scientific experiments.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	• Michael W. Davidson et al: Microscopy Primer, http://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 97150 Laser Technology

Modulcode	97150
Modultitel (deutsch)	Laser Technology
Modultitel (englisch)	Laser Technology
Modul-Verantwortliche/r	Dr. Kristian Cvecek (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every winter 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	• Physical phenomena applicable in Laser Technology: EM waves, Beam Propagation, Beam Interaction with matter • Fundamentals of Laser Technology: Principals of laser radiation, types and theoretical understanding of various types of lasers • Laser Safety and common applications: Metrology, Laser cutting, Laser welding, Surface treatment, Additive Manufacturing • Introduction to ultra-fast laser technologies • Numerical exercises related to above mentioned topics • Demonstration of laser applications at Institute of Photonic Technologies (LPT) and Bavarian Laser Centre (blz GmbH) • Possible Industrial visit (e.g. Trumpf GmbH, Stuttgart) • Optional: invited lecture about a novel laser application

Lern- und Qualifikationsziele	The student
	would know the fundamental principles involved in the development of lasers.
	will understand the design and functionality of various types of lasers, and be able to comprehend laser specifications.
	will be able to design and analyse a free space laser beam propagation setup.
	will gain knowledge about basic optical components used in laser setups such lenses, mirrors, polarizers, etc.
	would be able to understand the basic interaction phenomena during laser-matter interaction processes.
	would be able to determine the advantages and disadvantages of using laser process for industrial applications.
	will know and be able to apply the safety principles while handling laser setups.
	will be familiar with several most common industrial application of laser for material processing such as cutting, welding, material ablation, additive manufacturing.
	will be familiar with metrological applications of lasers.
	will become familiar with and be able to use international (English) professional terminology.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	120 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

Modul 763337 Laser Tissue Interaction

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every summer 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 (einschl. Prüfungsvorbereitungen)	90 h
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	The students can explain the basic properties of light using waveoptics The students can explain scattering mechanisms of light The students can explain the mechanisms of laser/tissue interaction

	The students can explain different methods for the modelling of light propagation in tissue
	The students can explain the RTE and apply MC for simulations of photon transport
	The students can explain and apply the basic procedures to determine the optical properties of tissue
	The students can explain the use and production of optical phantoms
	The students can explain 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 42140 Optical Lithography: Technology, Physical Effects and Modeling

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every summer 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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 semi-conductor chips are fabricated by optical projection lithogra-phy. Other lithographic techniques are used to fabricate litho- graphic masks or new optical and mechanical devices on the micro- or nanometer scale. Innovations such as the introduc-tion 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 pro-jection 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, disad-vantages, and limitations of lithographic methods are dis-cussed from different perspectives. Important components of lithographic systems, such as masks, projection systems, and photoresist will be

	described in detail. Physical and chemical effects such as the light diffraction from small features on ad-vanced photomasks, image formation in high numerical aperture systems, and coupled kinetic/ diffusion processes in mod-ern 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.
Lern- und Qualifikationsziele	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
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	• 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 44151 Medical Image Processing for Diagnostic Applications

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every 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 (einschl. Prüfungsvorbereitungen)	90 h
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	The participants • understand the challenges in interdisciplinary work between engineers and medical practitioners. • develop understanding of algorithms and math for diagnostic medical image processing. • learn that creative adaptation of known algorithms to new problems is key for their future career.

	• develop the ability to adapt algorithms to different problems.
	• are able to explain algorithms and concepts of the module to other engineers.
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 44141 Medical Image Processing for Interventional Applications

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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.
Lern- und Qualifikationsziele	The participants: • summarize the contents of the lecture. • apply pre-processing algorithms such as scatter correction and edge-preserving filtering. • extract information from images automatically by image analysis methods such as key point detectors and segmentation algorithms. • calibrate projection geometries for single images and image sequences using the described methods. • develop non-rigid registration methods using variational calculus and different regularizers. • adopt algorithms to new domains by appropriate modifications.
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 67143 Advanced nonlinear optics

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	Contents:* The goal of this lecture is to explore advanced concepts of nonlinear optics and their applications. This will cover the following topics: • Nonlinear propagation in solid-core photonic crystal fibres (modulation instability, four-wave mixing, soliton dynamics, supercontinuum generation) and in hollow-core photonic crystal fibres (generation of tunable dispersive waves, plasma in fibres) • Nonlinear optical effects (parametric down-conversion, four-wave mixing, modulation instability) for the generation of nonclassical light (entangled photons, squeezed light, twin beams, heralded single photons).

	• Nonlinear effects for generating high energy sub cycle pulses (kerr-lens mode-locking, Yb:YAG laser technology, optical parametric amplification, pulses synthesis, attosecond pulse generation)
Lern- und Qualifikationsziele	The students understand nonlinear propagation in solid-core and hollow-core photonic crystal fibers can analyze key nonlinear effects such as modulation instability, four-wave mixing, and soliton dynamics are familiar with nonlinear optical processes for generating nonclassical light, including entangled photons and squeezed states understand techniques for high-energy sub-cycle pulse generation, including Kerr-lens mode-locking and optical parametric amplification can apply advanced nonlinear concepts to modern laser technologies and ultrafast optics
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 67188 Quantum Communication

Modulcode	67188
Modultitel (deutsch)	Quantum Communication
Modultitel (englisch)	Quantum Communication
Modul-Verantwortliche/r	Prof. Dr. Christoph Marquardt (FAU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	In this seminar we will introduce and discuss fundamental concepts of quantum communication and talk about recent developments.
	Topics include: Introduction to quantum information concepts, quantum optics: preparation and measurement of quantum states, concepts of quantum cryptography and the BB84 protocol, quantum key distribution with discrete variables: modern protocols, QKD with continuous variables, modern quantum key distribution security proofs, quantum repeaters, quantum communication with satellites, quantum random number generation
Lern- und Qualifikationsziele	Students
	• comprehend an interesting physical topic in a short time frame
	• identify and interpret the appropriate literature
	• select and organize the relevant information for the presentation

	• compose a presentation on the topic at the appropriate level for the audience • use the appropriate presentation techniques and tools • criticize and defend the topic in a scientific discussion
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 43386 Computational Photography and Capture

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every summer 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	Never in human history have we been able to record so much of our environment in so little time with such high quality. Since the rise of smartphones, nearly everyone carries a powerful camera with them in their daily lives.
	This module introduces the theoretical and practical aspects of modern photography and capture algorithms: universal models of colour, computer-controlled cameras, lighting and shape capture.
	The lecture covers the following topics:
	• Cameras, sensors and colour
	• Image processing (e.g., blending, warping)
	• Radiometry
	• Appearance acquisition
	• Structured-light 3D acquisition

	• Image-based and video-based rendering
Lern- und Qualifikationsziele	The students
	understand the basic vocabulary of computational photography
	grasp the principles of light transport in natural scenes and digital image formation
	can explain how computational photography algorithms enhance traditional imaging techniques
	are familiar with image-processing algorithms for analyzing and transforming images
	can apply acquisition algorithms to capture appearances and reconstruct 3D scenes
	are able to develop their own software prototypes for capturing and processing digital images
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 713618 Computer vision

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every summer 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 (einschl. Prüfungsvorbereitungen)	90 h
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	The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants

	• describe perspective projection, rotations, and related geometric foundations,
	• explain the presented methods,
	• discuss the advantages and disadvantages of different modalities for acquiring 3-D information,
	• implement individually and in small groups code,
	• discover best practices in data acquisition,
	• explore and rank different choices for evaluation,
	• discuss and present in groups the advantages and disadvantages of their implementations,
	• discuss and reflect the social impact of applications of computer vision algorithms.
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	Englisch

Modul 42135 Image Processing in Optical Nanoscopy

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
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	• 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 44120 Pattern Analysis

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods. The topics comprise: • clustering methods: soft and hard clustering • classification and regression trees and forests • parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees • mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking

	• linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps
	• Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling
	• Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts
Lern- und Qualifikationsziele	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies, • implement presented methods in Python, • supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of pattern analysis solutions.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Begleitende Literatur / Accompanying literature: • 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 67156 Quantum Computing

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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.
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 "Quantum Computation and Quantum Information by Nielsen and Chuang (Cambridge Univ. Press), "Quantum Computating: A Gentle Introduction by Rieffel and Polak (MIT Press) as well as lecture notes by John Preskill available at http://theory.caltech.edu/~preskill/ph229/ and Ronald de Wolf available at https://homepages.cwi.nl/~rdewolf/qc19.html .
Unterrichtssprache	Englisch

Modul 67127 Nonlinear and Quantum Optics

Modulcode	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	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
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	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	Non-exhaustive list of topics for the seminar: • Two-photon absorption with entangled photons • Fibre sources of nonclassical light • Nanoscale quantum nonlinear optics • Sensing with undetected photons • Nonlinear optics with noble gases • The 'simplest' nonlinear optical system: a single atom • Quantum optics with parabolic mirrors • Machine Learning for Quantum State Estimation • Artificial Intelligence for Designing Quantum Optics Experiments and Photonic Devices

Lern- und Qualifikationsziele	Students • comprehend an interesting physical topic in a short time frame • identify and interpret the appropriate literature • select and organize the relevant information for the presentation • compose a presentation on the topic at the appropriate level for the audience • use the appropriate presentation techniques and tools • criticize and defend the topic in a scientific discussion
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 901895 Deep Learning

Modulcode	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
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Every 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 (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	Deep Learning (DL) has attracted much interest in a wide range of applications such as image recognition, speech recognition and artificial intelligence, both from academia and industry. This lecture introduces the core elements of neural networks and deep learning, it comprises: • (multilayer) perceptron, backpropagation, fully connected neural networks • loss functions and optimization strategies • convolutional neural networks (CNNs) • activation functions • regularization strategies

	• common practices for training and evaluating neural networks
	• visualization of networks and results
	• common architectures, such as LeNet, Alexnet, VGG, GoogleNet
	• recurrent neural networks (RNN, TBPTT, LSTM, GRU)
	• deep reinforcement learning
	• unsupervised learning (autoencoder, RBM, DBM, VAE)
	• generative adversarial networks (GANs)
	• weakly supervised learning
	• applications of deep learning (segmentation, object detection, speech recognition, ...)
	The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.
Lern- und Qualifikationsziele	The students • explain the different neural network components, • compare and analyze methods for optimization and regularization of neural networks, • compare and analyze different CNN architectures, • explain deep learning techniques for unsupervised / semi- supervised and weakly supervised learning, • explain deep reinforcement learning, • explain different deep learning applications, • implement the presented methods in Python, • autonomously design deep learning techniques and prototypically implement them, • effectively investigate raw data, intermediate results and results of Deep Learning techniques on a computer, • autonomously supplement the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of deep learning applications.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam

Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	• 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	Englisch

Modul PAFMO122 Biophotonics

Modulcode	PAFMO122
Modultitel (deutsch)	Biophotonics
Modultitel (englisch)	Biophotonics
Modul-Verantwortliche/r	Prof. Dr. Rainer Heintzmann (FSU), Prof. Dr. Ralf Ehricht (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization (Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics)
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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.
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Paras N. Prasad, Introduction to BiophotonicsTextbooks on laser spectroscopy, e.g. Demtröder; on quantum mechanics, e.g. Atkins and on optics, e.g. Zinth/ZinthJerome Mertz: Introduction to Optical Microscopy, Roberts & Company Publishers, 2010Selected 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)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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)
Häufigkeit des Angebots (Modulturnus)	Every summer semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS and Programming Lab 1 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Review: Linear Algebra, Calculus, Python• Optimization part 1: Continuous (Euler Lagrange) and Discrete (multivariate calculus)• Programming lab: genetic algorithms + Fermat principle• Optimization part 2: nonlinear optimization, regularization, Lagrange multipliers• Optimization part 3: Convex techniques, l1 minimization• Programming lab: single pixel camera• Optimization part 4: Automatic differentiation• Matrix representation of coherent optical systems Programming lab: keras toolbox, optical eigenmodes• Multiple scattering: Born / Rytov series, beam propagation method• Tomographic inversion • Programming lab: Foldy-Lax scattering theory• Phase retrieval part 1: coherent diffraction imaging (CDI)• Phase retrieval part 2: ptychography• Programming lab: hybrid input output, shrink wrap, ptychography• Phase retrieval part 3: Fourier ptychography• Image deconvolution: structured illumination microscopy, pupil engineering• Programming lab: extended depth-of-field systems• Imaging with

	spatially partially coherent light• Parameter estimation: Fisher information and Cramer Rao lower bound• Programming lab: Coded aperture imaging, resolution assessment, edge responses, modulation transfer function, Fourier ring correlation• Neural networks part 1: Image classification• Neural networks part 2: Image regression• Programming lab: digit recognition, counting red blood cells
Lern- und Qualifikationsziele	Understanding the interplay between forward and inverse modeling in optical systems. Hands-on programming skills.
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 PAFMO130 Computational Photonics

Modulcode	PAFMO130
Modultitel (deutsch)	Computational Photonics
Modultitel (englisch)	Computational Photonics
Modul-Verantwortliche/r	Prof. Dr. T. Pertsch (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization (Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics)
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Taflove and S.C. Hagness, Computational Electrodynamics
Unterrichtssprache	Englisch

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	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization (128 M.Sc. Physics: Required elective module 128 M.Sc. Photonics: Required elective module)
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	The students understand light propagation in nonlinear media and the role of the nonlinear susceptibility tensor can describe and analyze parametric effects and second harmonic generation

	grasp the concept of phase-matching and its importance in nonlinear optical processes
	are familiar with ultrashort pulse propagation and high-harmonic generation
	can explain soliton formation and its relevance in nonlinear optics
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	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	Students understand the fundamental properties and light propagation in optical fibers are familiar with fiber fabrication, characterization techniques, and special fiber types can analyze fiber-based devices such as amplifiers and lasers

	understand key applications of optical fibers in communication, sensing, and laser technology
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Snyder/Love, Optical Waveguide Theory; Okamoto, Fundamentals of Optical Waveguides.
Unterrichtssprache	Englisch

Modul PAFMO170 High-Intensity/ Relativistic Optics

Modulcode	PAFMO170
Modultitel (deutsch)	High-Intensity/ Relativistic Optics
Modultitel (englisch)	High-Intensity/ Relativistic Optics
Prof. Dr. M. Kaluza	Prof. Dr. M. Kaluza (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	High-intensity laser technology;Laser plasma physics;Laser accelerated particles and applications.
Lern- und Qualifikationsziele	The students understand the principles of high-intensity laser technology and its key components are familiar with laser-plasma interactions and their physical foundations can analyze laser-driven particle acceleration and its applications in science and technology
Voraussetzung für die Zulassung zur Modulprüfung	-

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summer semester
Dauer des Moduls	1 Semester
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS and exercise 2 SWS
Leistungspunkte (ECTS credits)	4 LP
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Gonzalez, Woods, Digital Image Processing, Prentice Hall, 2001
Unterrichtssprache	Englisch

Modul PAFMO181 Image Processinng 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	None
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)	MSc. Photon Science and Technology: Required Elective Course Specialization

Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics |
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

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	None
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on modern optics and condensed matter physics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every wintersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
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 Quantum Photonics

Modulcode	PAFMO184
Modultitel (deutsch)	Integrated Quantum Photonics
Modultitel (englisch)	Integrated Quantum Photonics
Modul-Verantwortliche/r	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	Every wintersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
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• 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	The course should provide the participating students with a profound knowledge on the state of the art of integrated optics used for the realization of quantum optical devices.After active participation in the course, the students will be familiar with the basic concepts and phenomena of integrated quantum photonics and will be able to

	develop own concepts for integrated quantum circuitry.The intended learning outcome is that the students are introduced to the basics on the field of integrated quantum optics and its applications.Therefore, course starts with an overview on the generation of non-classical states of light with special attention on integrated solutions.Afterwards several integrated photonic platforms will be discussed ranging from fabrication to performance and useability.Based on that the on-chip manipulation of non-classical states of light will be discussed. This starts with the very general concept of quantum walks and continues towards quantum simulation. It ends with an introductory to photonic quantum computing with a clear focus on practical implementation of quantum photonic gate structures.The course closes with the discussion on non- classical light detection in integrated photonics.
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 PAFMO185 Innovation Methods in Physics	
Modulcode	PAFMO185
Modultitel (deutsch)	Innovation Methods in Physics
Modultitel (englisch)	Innovation Methods in Physics
Modul-Verantwortliche/r	Prof. Dr. T. Pertsch (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	Every wintersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	The students will learn how the results of their scientific research can be turned into relevant innovations as an important part of their future career. On the one hand, the course will enable students to understand and to drive innovation processes in photonics companies. On the other hand, students will develop an entrepreneurial skill set for the independent economical exploitation of scientific ideas.Therefore, the course introduces the basic knowledge on innovation management, entrepreneurship, and intellectual property rights. To practice their skills, the students will also conduct their own photonics innovation project during the semester by working hands-on in small teams in the photonics makerspace Lichtwerkstatt. During this practical part, they

	acquire and apply a thorough knowledge of photonic rapid prototyping technologies (e.g. 3d- scanning and printing, laser cutting, microcontrollers, ...) and the most important creativity methods and project management skills. To cover this range of topics, the course will be supported by guest lecturers from different sectors (academia, industry).
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 PAFMO205 Light and Microscopy

Modulcode	PAFMO205
Modultitel (deutsch)	Light Microscopy
Modultitel (englisch)	Light Microscopy
Modul-Verantwortliche/r	Prof. Dr. Rainer Heintzmann (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every winter semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Starting from geometrical optics the imaging system will be described and optical aberrations will be discussed. Moving on to wave optics monochromatic waves will be taken as the basis for the description of coherent imaging. Combined with scattering theory in the 1st Born approximation a fundamental understanding of the possibilities and limitations in imaging is gained. The concept of the amplitude transfer function and McCutchens 3-dimensional pupil function are introduced. On this basis various coherent imaging modes are discussed including holographic approaches and their limitations, and optical coherent tomography. The working principles of light-detectors are discussed and the requirements for appropriate sampling of images. Finally various modes of fluorescence microscopy and high- resolution microscopy will be covered. The exercises will be calculating examples, also involving hands-on computer based modeling using Matlab and other tools.

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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

Modul PAFMO220 Micro/Nanotechnology

Modulcode	PAFMO220
Modultitel (deutsch)	Micro/Nanotechnology
Modultitel (englisch)	Micro/Nanotechnology
Modul-Verantwortliche/r	Apl. Prof. Uwe Zeitner (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

Modul PAFMO221 Microscopy

Modulcode	PAFMO221
Modultitel (deutsch)	Microscopy
Modultitel (englisch)	Microscopy
Modul-Verantwortliche/r	Prof. Dr. R. Heintzmann (FSU), Prof. Dr. C. Eggeling (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Optical microscopy, Circumventing the resolution limit, Electron microscopy, Atomic force microscopy
Lern- und Qualifikationsziele	The students: understand the principles of optical, electron, and atomic force microscopy can explain techniques for surpassing the optical resolution limit are familiar with the working principles and applications of advanced microscopy methods can compare different microscopy techniques in terms of resolution, contrast, and application areas

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 PAFMO260 Quantum Optics

Modulcode	PAFMO260
Modultitel (deutsch)	Quantum Optics
Modultitel (englisch)	Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. T. Pertsch (FSU), Dr. F. Setzpfandt (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on theoretical optics, electrodynamics and quantum theory
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every Summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	The course will give a basic introduction into the theoretical description of quantized light and quantized light-matter interaction. The derived formalism is then used to examine the properties of quantized light and to understand a number of peculiar quantum optical effects.After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum optics and will be able to apply the derived formalism to other problems.
Voraussetzung für die Zulassung zur Modulprüfung	-

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
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	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. T. Pertsch (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	Every summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	The students understand the fundamental concepts of quantum computation and qubits for information processing can analyze and implement key quantum algorithms, including Shor's and Grover's algorithms

	are familiar with multipartite quantum systems and the concept of entanglement
	can evaluate real-world implementations of quantum computers and their applications
	are able to assess and develop quantum algorithms for practical use cases
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 PAFMO262 Quantum Communication

Modulcode	PAFMO262
Modultitel (deutsch)	Quantum Communicaton
Modultitel (englisch)	Quantum Communicaton
Modul-Verantwortliche/r	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. A. Tünnermann (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	Goals: The course will give a basic introduction into the usage of quantum states of light for the exchange of generation of quantum light and schemes that leverage these states for the exchange of information, ranging from fundamental concepts and experiments to state of the art implementations for secure communication networks. The course will also give an outlook to aspects of Quantum metrology and imaging.After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical

	implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.
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 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)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	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
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	Goals: The course will give a basic introduction into the usage of quantum light, in particular photon pairs, for imaging and sensing. To this end, many basic concepts and applications will be introduced and discussed. Furthermore, students will learn how to mathematically describe quantum sensing schemes in order to understand and predict their propreties.After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum imaging and sensing and will be able to apply the derived formalism to similar problems.

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 PAFMO265 Semiconductor Nanomaterials

Modulcode	PAFMO265
Modultitel (deutsch)	Semiconductor Nanomaterials
Modultitel (englisch)	Semiconductor Nanomaterials
Modul-Verantwortliche/r	Prof. Dr. Isabelle Staude (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on modern optics and condensed matter physics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Required elective Module M.Sc. Physics focus „Optics" Required elective Module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	The course will cover the following topics: Review of fundamentals of semiconductors, Optical and optoelectronic properties of semiconductors, Effects of quantum confinement, Photonic effects in semiconductor nanomaterials, Physical implementations of semiconductor nanomaterials, including epitaxial structures, semiconductor quantum dots and quantum wires, Advanced topics of current research, including 2D semiconductors and hybrid nanosystems
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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
Unterrichtssprache	Englisch

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 (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam

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 (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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 students understand the types and symmetries of nonlinear polarization can analyze nonlinear optical effects in waveguides are familiar with solutions of nonlinear evolution equations understand the formation of temporal and spatial solitons can explain the principles of supercontinuum generation

Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	30 min oral exam
Zusätzliche Informationen zum Modul	The grade is composed of the performance in the exercise classes (25%) and an oral exam (30 min, 75%).
Empfohlene Literatur	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	None
Empfohlene bzw. erwartete Vorkenntnisse	Fundamental knowledge on optics and Electrodynamics of continua
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every wintersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Basic dispersion models in Thin Film Optics, Optical properties of material mixtures, Interfaces: Fresnels equations, Multiple internal reflections in layered systems, Optical spectra of single thin films, Wave propagation in stratified media, Matrix formalism, Multilayer systems: Quarterwave-stacks and derived systems, Coatings for ultrashort light pulses, Remarks on coating design
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 Zulassung zur Modulprüfung	-

Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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. G. Paulus (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every summer semester
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 (einschl. Prüfungsvorbereitungen)	75 h
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.
Lern- und Qualifikationsziele	The students

	understand the fundamentals of terahertz (THz) radiation and its interaction with matter
	are familiar with various THz generation techniques, with a focus on pulsed power sources
	can analyze and compare electronic and photonic THz detection methods
	understand the selection of appropriate optical components and materials for THz applications
	can evaluate THz applications in imaging, spectroscopy, and related fields
Voraussetzung für die Zulassung zur Modulprüfung	Handing in exercise sheets (in a way that will be specified at the beginning of the semester)
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	Principles of terahertz Science and Technology, Lee, Yun-Shik , Springer ,ISBN 978-0-387-09540-0Terahertz techniques, Bründermann, Hubers, Kimmit, Springer, ISBN 978-3-642-02592-1Introduction to THz wave photonics, Zhang, Xu, Springer, ISBN 978-1- 4419-0978-7Journals: 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 (FSU)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	Basic knowledge in laser physics and modern optics.
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every wintersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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	Presentation
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam

Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	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)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	Fiber Optics and Ultrafast Optics
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
	128 MSc. Physics: required elective module in the specialization optics628 MSc Photonics: required elective module
Häufigkeit des Angebots (Modulturnus)	Every summersemester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	The course will cover the following topics: Review of fundamentals of ultrafast fibre lasers (mode-locking and Q-switching Engineering of fibre laser cavities Ultrashort pulse characterization (autocorrelatioon, FROG, dispersive Fourier transformation, etc.)Extreme phenomena, exploration of new wavelength rangesand other latest technology advancements in ultrafast fibrelaser developmentDetailed overview of the ultrafast laser applications in industry,sensing, and medicine (diagnostics and treatment)
Lern- und Qualifikationsziele	The students

understand the fundamentals of ultrafast fibre lasers, including mode-locking and Q-switching |

	can analyze and design fibre laser cavities for ultrashort pulse generation are familiar with pulse characterization techniques such as autocorrelation and FROG can explain extreme phenomena and advances in ultrafast fibre laser technology understand key applications of ultrafast fibre lasers in industry, sensing, and medicine
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)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

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	None
Empfohlene bzw. erwartete Vorkenntnisse	-
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization 128 Mandatory elective module M.Sc. Physik in der Vertiefung „Optik" 628 Mandatory elective module M.Sc. Photonics
Häufigkeit des Angebots (Modulturnus)	Every semester
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 (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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.
Lern- und Qualifikationsziele	The students understand the complex refractive index in the XUV and X-ray range can analyze refractive, grazing incidence, and zone plate optics are familiar with X-ray diffraction and scattering phenomena understand applications in plasma diagnostics and EUV lithography
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

2.1 Module: Adaptive Optics [M-ETIT-103802]

Modulcode	M-ETIT-103802
Modultitel (deutsch)	2.1 Module: Adaptive Optics
Modultitel (englisch)	2.1 Module: Adaptive Optics
Modul-Verantwortliche/r	Prof. Dr. Ulrich Lemmer (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	Adaptive optics is a technology of correcting the effect of atmospheric turbulence on images of space objects and on laser

beams propagating through random and highly aberrated media such as turbulence, tissue, and the inside of the human eye, to

name just a few applications. The course will familiarize the students with theoretical basics of light propagation through random

media, principles of wavefront sensing and reconstruction, as well as wavefront correction with deformable mirrors. The

students will also receive solid introduction to statistical optics, the Kolmogorov theory of turbulence, practical aspects of

turbulence simulation and modelling of adaptive optics.

Theory of turbulence (covariances, structure functions, power spectra, inertial range, dimensional argument of |

	Kolmogorov)
	Fourier optics (point-spread function, modulation transfer function)
	Statistical optics (characteristic function, probability density function)
	Sources and description of aberrations (Zernike polynomials, orthogonality, Marechal criterion)
	Adaptive optics systems (open- and closed-loop systems, error budgets, tip-tilt correction)
	Wavefront sensing (Shack-Hartmann wavefront sensor, wavefront reconstruction, wavefront-sensorless AO)
	Wavefront correction (tip-tilt mirrors, deformable mirrors, piezoelectric effect, microelectromechanical systems,
	electrostatic actuation)
	Simulation of adaptive optical systems (analytic vs. end-to-end modelling)
	Propagation of laser beams through atmospheric turbulence (Gaussian beams, Rytov theory, scintillation index, beam
	wander)
	Modelling of free-space optical communication systems (aperture averaging, mean signal-to-noise ratio, false-alarm rate
	and fade probability, bit error-rate)
Lern- und Qualifikationsziele	The students will:
	get familiar with Fourier description of imaging through aberrated optical systems and random media,
	understand the description of aberrations through Zernike modes,
	learn how to analytically compute the effects of turbulence on various optical observables such as image/beam motion,
	temporal power spectra, Zernike modes, scintillation, etc.,
	understand the effect of noise on various quantities and metrics pertinent to the design of adaptive optical systems,
	understand the advantages and disadvantages of various schemes for wavefront sensing and correction,
	learn how to simulate and design simple adaptive optics systems.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: Oral examination
	Duration of Examination: approx. 30 Minutes
	Modality of Exam: The oral exam will be scheduled during the semester break.

Zusätzliche Informationen zum Modul	-	
Empfohlene Literatur	-	Robert K. Tyson, Principles of Adaptive Optics, CRC Press
	-	Michael C. Roggemann, Byron M. Welsh, Imaging through Turbulence, CRC
	-	Press
Unterrichtssprache	Englisch	

2.2 Module: Advanced Inorganic Materials [M-CHEMBIO-101901]

Modulcode	M-CHEMBIO-101901
Modultitel (deutsch)	2.2 Module: Advanced Inorganic Materials
Modultitel (englisch)	2.2 Module: Advanced Inorganic Materials
Modul-Verantwortliche/r	Prof. Dr. Claus Feldmann (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	2 terms
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	45 h
Inhalte	Selected aspects of modern functional inorganic materials, including: • High-temperature ceramics and hard materials • Color pigments – from Egyption blue to 2D Bragg stacks • Phosphors, luminescence, spectroscopy • Fast ion conductors and high-power batteries • Superconductors: metals, alloys, oxocuprates and current developments • Porous networks: from zeolites to metalorganic frameworks (MOFs) • Transparent conductive oxides and dye-sensitized solar cells • Magnetic pigments: magnetic recording, superparamagnetism and magnetothermal therapy

	• Modern thermoelectric materials
	• Fullerenes and fibre-reinforced composite materials
	• Nanomaterials: Quantum Dots, hollow spheres and nanotubes
	. . . and other examples of advanced functional materials
Lern- und Qualifikationsziele	The students refresh and elaborate their knowledge on inorganic materials, materials chemistry as well as basic inorganic
	chemistry and solid state chemistry. This comprises fundamental aspects of the chemistry of the elements as well as state-ofthe-
	art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence)
	of inorganic functional materials.
	The students
	• get familiar with basic inorganic chemistry and solid state chemistry
	• get familiar with concepts of describing crystal structures
	• know how to characterize inorganic solid compounds and materials
	• learn how to prepare inorganic compounds and solid materials
	• understand general aspects of structure-property relations
	• comprehend general concepts of solid state chemistry and inorganic functional materials
	• are able to rationalize fundamental properties of inorganic materials
	know general trends in view of a technical application of advanced inorganic materials
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.4 Module: Automotive Vision [M-MACH-102693]

Modulcode	M-MACH-102693
Modultitel (deutsch)	2.4 Module: Automotive Vision
Modultitel (englisch)	2.4 Module: Automotive Vision
Modul-Verantwortliche/r	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 3 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	135 h
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 semantically. This comprises, binocular reconstruction, recognition of 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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- TBA
Unterrichtssprache	Englisch

2.6 Module: Business Innovation in Optics and Photonics [M-ETIT-101834]

Modulcode	M-ETIT-101834
Modultitel (deutsch)	2.6 Module: Business Innovation in Optics and Photonics
Modultitel (englisch)	2.6 Module: Business Innovation in Optics and Photonics
Modul-Verantwortliche/r	Prof. Dr. Werner Nahm (KIT)
Voraussetzung für die Zulassung zum Modul	none
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	34 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	86 h
Inhalte	This course is instructed and presented by external innovation specialists of the R&D, business and management departments of the Carl Zeiss AG.

Introduction: Examples of existing smart mobile device applications, Brainstorming for ideas

Technology Introduction: Mobile device technology, Optic components, Display technology (LCD, OLED), Tracking and

Sensor Technologies in smart mobile devices

Group Work Technology

Group Presentations Technology

Business Case Development/ Business Plan: Market segmentation, Market research, Essentials of finance, How to write |

	a business plan?
	Management of Intellectual Property (IP): Importance of IP Management, Patent research, Patent claims, Licencing,
	Patent infringement, Patent litigation
	Project Design: How to run an agile R&D Project?, Traget costing, Networked product development
	Agile project simulation
	Group Work
	Excursion to Carl Zeiss AG in Oberkochen (full day)
	Presentation of results of the group work to the new business experts committee of the Carl Zeiss AG
Lern- und Qualifikationsziele	The student has an understanding how innovative concepts for optical and photonics products are transferred into a successful
	business development. The student knows about and makes first hands on experiences on business development aspects in a
	technology start up environment. The students acquire specialized knowledge in technologies and applications in the field of
	smart mobile solutions for optical applications as well as an introduction into the field of patent rights.
	The students can organize themselves in groups and distribute and execute tasks. Further they gain competences in the fields
	teamwork, organization and communication.
	The studetns
	understand the implications of intellectual property
	are able to perform data base research
	know how to develop a business plan
	get an understanding of how to design a project
	are able to develop in small groups innovative business cases for a potential future product
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: examination of another type
	Duration of Examination: 4 group presentations à 20 minutes (approx.)
	Modality of Exam: The exam consists of four group presentations. 2nd day: Technology Presentation. 3rd day: Development
	plan presentation. 4th day: Business Canvas presentation. Final presentation at Zeiss visit: Business pitch
Zusätzliche Informationen zum Modul	-

| Empfohlene Literatur | - |
| Unterrichtssprache | Englisch |

2.7 Module: Computational Photonics, without ext. Exercises [M-PHYS-103089]

Modulcode	M-PHYS-103089
Modultitel (deutsch)	2.7 Module: Computational Photonics, without ext. Exercises
Modultitel (englisch)	2.7 Module: Computational Photonics, without ext. Exercises
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Irregular
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	Transfer Matrix Method to describe the optical response from stratified media
	Finite Differences to characterize eigenmode in fiber waveguides
	Beam propagation method to describe the evolution of light in the realm of integrated optics
	Grating methods to predict reflection and transmission from periodically arranged material in 1D and 2D
	Mie Theory to describe the scattering of light from individual cylindrical or spherical objects
	Finite-Difference Time-Domain method as a general purpose tool to solve micro- and nanooptical problems
	Multiple Multipole Method as an approach to describe light scattering from single objects with an arbitrary shape

	Greens' Methods to discuss equally the scattering from single objects but embedded in an inhomogeneous background
	Boundary Integral Method to discuss scattering from objects highly efficient using expressions for the fields on the
	surface
Lern- und Qualifikationsziele	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.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral Exam. The total duration of the oral exam is approx. 60 minutes.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- "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

2.8 Module: Digital Signal Processing in Optical Communications – with Practical Exercises [M-ETIT-103450]

Modulcode	M-ETIT-103450
Modultitel (deutsch)	2.8 Module: Digital Signal Processing in Optical Communications – with Practical Exercises
Modultitel (englisch)	2.8 Module: Digital Signal Processing in Optical Communications – with Practical Exercises
Modul-Verantwortliche/r	Prof. Dr.-Ing. Sebastian Randel (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS, Exercise class 2 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	The module deals with algorithms from digital signal processing that are used in broadband optical communication systems. Practical exercises in which the students implement algorithms independently form an essential part of the module. In lectures there will be an introduction to the development of digital coherent transmitters and receivers. Building on this, essential function blocks such as the dispersion compensation, the adaptive equalization of polarization mode dispersion as well as carrier and clock recovery are discussed.

	In the exercises, these function blocks are to be implemented in software (Matlab, Octave). In addition, individual examples show how digital signal processing algorithms are described in hardware (Hardware Description Language - HDL) and how their complexity scales.
Lern- und Qualifikationsziele	The students understand the functioning of modern optical communication systems, which combine electro-optical technologies with digital signal processing. You are able to independently implement and test algorithms from digital signal processing as well as suitable simulation and test environments in a suitable scripting language (e.g. Matlab or. Python). Furthermore, they can estimate the influence of interfering effects occurring in the glass fiber such as chromatic dispersion and polarization mode dispersion. You are also able to estimate the complexity and power consumption of the resulting logic circuits.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	The exercise sheets and the oral questionnaire are used to rate other types of examinations. The overall impression is assessed. Duration about 20 minutes.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

2.10 Module: Electromagnetics and Numerical Calculation of Fields [METIT-100386]

Modulcode	METIT-100386
Modultitel (deutsch)	2.10 Module: Electromagnetics and Numerical Calculation of Fields
Modultitel (englisch)	2.10 Module: Electromagnetics and Numerical Calculation of Fields
Modul-Verantwortliche/r	Prof. Dr.-Ing. Thomas Zwick (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
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 Methal (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	Students with very different background in electromagnetic field theory will be brought to a high level of comprehension. They
	will understand the concept of electric & magnetic fields and of electric potential & vector potential and they will be able to solve
	simple problems of electric & magnetic fields using mathematics. They will understand the equations and solutions of wave
	creation and wave propagation. Finally the student will have learnt the basics of numerical field calculation and be able to use
	software packages of numerical field calculation in a comprehensive and critical way.
	The student will
	be able to deal with all quantities of electromagnetic field theory (E, D, B, H, J, M, P, ...), in particular: how to calculate
	and how to measure them,
	derive various equations from the Maxwell equations to solve simple field problems (electrostatics, magnetostatics,
	steady currents, electromagnetics),

	be able to deal with the concept of field energy density and solve practical problems using it (coefficients of capacitance and coefficients of inductance), be able to derive and use the wave equation, in particular: to solve problems how to create a wave and calculate solutions of wave propagation through various media, be able to outline the concepts, the main application areas and the limitations of methods of numerical field calculation (FDM, FDTD, FIM, FEM, BEM, MoM, TLM) be able to use one exemplary software package of numerical field calculation and solve simple practical problems with it.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Success control is carried out in the form of a written test of 120 minutes.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.11 Module: Fabrication and Characterisation of Optoelectronic Devices [METIT-101919]

Modulcode	METIT-101919
Modultitel (deutsch)	2.11 Module: Fabrication and Characterisation of Optoelectronic Devices
Modultitel (englisch)	2.11 Module: Fabrication and Characterisation of Optoelectronic Devices
Modul-Verantwortliche/r	Prof. Dr. Bryce Sydney Richards (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	I. Overview: Opto-electronic Devices II. 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) III. Lithographic techniques e-beam lithography, optical lithography, laser interference lithography, two-photon lithography, X-ray lithography

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IV. Etching processes

wet- and dry-etching processes for semiconductors, dielectrics and metals

V. Micro-optics

micro-optic design in opto-electronic devices

VI. Characterissation:

materials properties (electron microscopy, crystallinity, bonding energies, elemeental concentrations, layer

thicknesses ...)

electronic properties (dopant profiling, mobility, minority carrier lifetimes, resistivity, bandgap measurements, ...)

optical (spectrophotometry, photoluminescence, ...)

electrical (current-voltage measurements, quantum efficiency / spectral response, ...)

VII. Excursion (TBA)

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<tr><td>Lern- und Qualifikationsziele</td><td>

The students build knowledge on process technology for the fabrication of a range of optoelectronic devices, including LEDs,

solar cells, laser diodes, photodiodes, etc. They learn to compare the advantages of different technological approaches,

including their economic boundary conditions. This is a technologiccal-based course where students will use their prior

fundamental knowledge to gain a firm grasp on the fabrication sequences and characterisation (optical, electrical, electronic,

materials) steps that are required to realise the above devices. While fulfilling the learning targets, the students

possess the basic knowledge about the working principles of optoelectronic devices;

comprehend the boundary conditions for the design of optoelectronic devices and have a good understanding of the

challenges in microfabrication

are familiar with different lithographic techniques, including e-beam lithography, optical lithography, multiple-photon

lithography, X-ray lithography, etc.

comprehend the different techniques that are available for thin-film deposition of dielectrics, metals and semiconductors

understand what role micro-optics can play in such devices

be able to determine the most promising characterisation techniques for evaluating material quality, electronic properties,

as well as optical and electrical performance.

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	Exposure to different dry- and wet-etching processes to help realise device structures
	have an understanding of the economic implications of the chosen technologies and their compatibility with
	highthroughput production
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: written exam Duration of Examination: 120 Minutes Modality of Exam: One written exam offered at the end of each semester.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

2.12 Module: Field Propagation and Coherence [M-ETIT- 100566]

Modulcode	M-ETIT- 100566
Modultitel (deutsch)	2.12 Module: Field Propagation and Coherence
Modultitel (englisch)	2.12 Module: Field Propagation and Coherence
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS, Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	The following selection of topics will be presented:
	Light waves, modes and rays: Longitudinal and transverse modes, sampling theorem, counting and density of modes
	("states")
	Propagation in multimode waveguides. Near-field and far-field. Impulse response and transfer function. Perurations and
	mode coupling. Multimode interference (MMI) coupler. Modal noise (speckle)
	Propagation in homogeneous media: Resolution limit. Non-paracial and paracial optics. Gaussian beam. ABCD matrix
	Coherence of optical fields: Coherence function and power spectrum. Polarisation, eigenstates and principal states.

	Measurement of coherence with interferometers (Mach-Zehnder, Michelson). Self-heterodyne and self-homodyne setups
Lern- und Qualifikationsziele	Presenting in a unified approach the common background of various problems and questions arising in general optics and
	optical comunications
	The students
	knwo the common properties of counting of modes, density of states and the sampling theorem
	comprehend the relationship between propagation in multimode waveguides, mode coupling, MMI and speckles
	can analyze propagation in homogeneous media with respect to system theory, antennas, and the resolution limit of
	optical instruments
	understand that coherence as a general concept comprises coherence in time, in space and in polarisation
	comprehend the implication of complete spatial incoherence, and what is the radiation efficiency of a source with a
	diameter smaller than a wavelength (the mathematical Hertzian dipole, for instance)
	can assess when can two incandescent bulbs form an interference pattern in time
	know under which conditions a heterodyne radio receiver, which is based on a non-stationary interference, actually
	works
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: oral exam
	Duration of Examination: approx. 30 minutes
	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.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- Detailed lecture notes as well as the presentation slides can be downloaded from the IPQ lecture pages. Additional reading: - Born, M.; Wolf, E.: Principles of optics, 6. Aufl. Oxford: Pergamon Press 1980 - Ghatak, A.: Optics, 3. Ed. New Delhi: Tata McGraw Hill 2005 - Hecht, E.: Optics, 2. Ed. Reading: Addison-Wesley 1974

	- Hecht, J.: Understanding fiber optics, 4. Ed. Upper Saddle River: Prentice Hall 2002 - Iizuka, K.: Elements of photonics, Vol. I and II. New York: John Wiley & Sons 2002 - Further textbooks in German (also in electronic form) can be named on request
Unterrichtssprache	Englisch

2.24 Module: Imaging Techniques in Light Microscopy [M-CHEMBIO-101905]

Modulcode	M-CHEMBIO-101905
Modultitel (deutsch)	2.24 Module: Imaging Techniques in Light Microscopy
Modultitel (englisch)	2.24 Module: Imaging Techniques in Light Microscopy
Modul-Verantwortliche/r	Prof. Dr. Martin Bastmeyer (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	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. I. Introduction (History and Basic Principles of Compound Microscopes, Resolution and Contrast, Biological Sample Preparation) II. Imaging Modes and Contrast Techniques (Biological Amplitude and Phase Objects, Phase Contrast, Interference Contrast, Polarization Microscopy) III. Fluorescence Microscopy (Microscopic Principles, Fluorescent Dyes and Proteins, Biological Sample Preparation)

	IV. Laser-Scanning-Microscopy (Basic Principles, Spinning Disk, 2-Photon Microscopy, Optical Sectioning Techniques)
	V. Live Cell Imaging (Video Microscopy, Fluorescent Proteins)
	VI. Special Fluorescence Techniques (FRET, TIRF, FCS)
	VII. Super Resolution Microscopy (SIM, PALM, dSTORM, STED)
	VII. Digital images (Image Processing, Data Analysis and Quantification)
Lern- und Qualifikationsziele	The students • are able to derive the description of geometric- and wave-optical principles of a compound microscope • know the physical principles of fluorescent dyes • understand the configuration of laser scanning microscopes • comprehend digital imaging and image processing • have experienced a hands on laboratory praxis of the different microscopic techniques • understand the biological principles of GFP-expression • know the latest developments in light microscopy • understand how technical development of microscopes has driven basic biological research
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Written exam over 120 minutes (depending on the number of participants oral exam over approx.45 min). Modality of Exam: Depending on the number of participants, a written or an oral exam is accomplished. The exact modality of the exam will be announced at the beginning of the semester. The written exam is scheduled for the beginning of the break after the WS. A resit exam is offered at the end of the break.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- Lecture presentations will be accessible in pdf-format - Recent review articles will be distributed before the lectures - Books: - Alan R. Hibbs: Confocal Microscopy for Biologists, Springer Press - Rafael Yuste (Ed.): Imaging, a laboratory manual, CSH Press - James Pawley: Handbook of biological confocal microscopy, Plenum Press
Unterrichtssprache	Englisch

2.30 Module: Light and Display Engineering [M-ETIT-100512]

Modulcode	M-ETIT-100512
Modultitel (deutsch)	2.30 Module: Light and Display Engineering
Modultitel (englisch)	2.30 Module: Light and Display Engineering
Modul-Verantwortliche/r	Dr.-Ing. Rainer Kling (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Tutorium 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Motivation: Light & Display Engineering
	Light, the Eye and the Visual System (including Melatonin)
	Fundamentals in Light Engineering
	Light in non - visual Processes (UV Processes)
	Color and Brightness
	Light Sources (Halogen, Low Pressure and High Pressure Lamps, LED Engines) and electronic Drivers
	Displays (Active and Passive Displays: AMOLED, E-ink, TFT Display, Plasma Display)
	Luminaries (Fundamentals, Design Rules, Simulations)
	Optical Design (Ray tracing, Reflector design, Computed Ray tracing)

Lern- und Qualifikationsziele	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
	displays. The course gives a broad overview how optics can be applied in modern technology fields. The subjects taught are
	further clarified by demonstrations, models and experiments.
	The students
	can derive the description of basic of light engineering starting from the eye and the visual system
	know how to handle basic metrical units and know how to measure them
	understand the visible sensing in contrast to radiation measurements
	comprehend the concepts of colour and colour control
	are familiar with all types of light sources from low pressure lamps to LED modules
	conceive the operation principle of various types of drivers
	know how to set up a luminaire and how simulate a reflector
	they understand how active (Plasma Displays) and passive displays (TFT Display) work and how to operate them
	have a good visualization of numerous optical design approaches
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	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.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.31 Module: Lighting Design - Theory and Applications [M-ETIT-100577]

Modulcode	M-ETIT-100577
Modultitel (deutsch)	2.31 Module: Lighting Design - Theory and Applications
Modultitel (englisch)	2.31 Module: Lighting Design - Theory and Applications
Modul-Verantwortliche/r	Dr.-Ing. Rainer Kling (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Seminar 3 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	45 h
Inhalte	1. Lighting Design - Introduction form all over the world
	2. Lighting Fundamentals
	3. Lighting Design Theory
	4. Energy Savings and Lighting design
	5. Lighting Design Tools
	6. Computing Standards
	7. Lighting Design Applications (Practical Part)
	7.1 Interior Lighting
	7.2 Exterior lighting
	7.3 IlluminationOwn Calculation Examples (Practical Part)Motivation: Light & Display Engineering

	8. Own Calculation Examples (Practical Part)Motivation: Light & Display Engineering
Lern- und Qualifikationsziele	The students will apply a comprehensive knowledge of Lighting Design from theory, standards and applications in Indoor and
	Outdoor lighting. Examples and own Lighting design examples as projects. So a practical and theoretical background is applied
	to Lighting Design. From metrics too Light Planning projects in small exercise groups. The subjects taught are further clarified by
	demonstrations, models and experiments. Attending students get the knowledge to Lighting Design, in a shorter theoretical part
	and practical lighting design simulations with examples from all over the world.
	The students
	can derive the description of basics of Lighting Design
	know how to handle basic metrical units and know how to measure them
	understand the Lighting Design metrics to apply on projects
	have a good visualization of numerous design approaches
	realize good Lighting Design with codes and standards.
	can see energy savings levels for Lighting Design
	comprehend the lighting design by practical self-computing lessons:
	can realize own indoor Lighting design concepts for different applications like Office, School, Shops, Gyms & Industry
	can realize own outdoor Lighting Design concepts for Street lighting, Tunnels, Stade and Parkings
	can use for realization Relux and Dialux light planning software so set up Project Planning for Lighting Design.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	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.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- J. Livingstone: Designing With Light: The Art, Science and Practice of Architectural Lighting Design, 2014 - S. Russel: The Architecture Of Light: Interior Designer and Lighting Designer, 2012 - M. Karlen: Lighting Design Basics, Indoor Lightin, 2004

	- R.H. Simons Lighting Engineering, 2001Simons, Lighting Engineering: Applied Calculations, 2001 - R. Winchip, Fundamentals of Lighting, 2nd Edition, 2011
Unterrichtssprache	Englisch

2.2 Module: Advanced Inorganic Materials [M-CHEMBIO-101901]

Modulcode	M-CHEMBIO-101901
Modultitel (deutsch)	2.2 Module: Advanced Inorganic Materials
Modultitel (englisch)	2.2 Module: Advanced Inorganic Materials
Modul-Verantwortliche/r	Prof. Dr. Claus Feldmann (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	45 h
Inhalte	Selected aspects of modern functional inorganic materials, including: • High-temperature ceramics and hard materials • Color pigments – from Egyption blue to 2D Bragg stacks • Phosphors, luminescence, spectroscopy • Fast ion conductors and high-power batteries • Superconductors: metals, alloys, oxocuprates and current developments • Porous networks: from zeolites to metalorganic frameworks (MOFs) • Transparent conductive oxides and dye-sensitized solar cells • Magnetic pigments: magnetic recording, superparamagnetism and magnetothermal therapy • Modern thermoelectric materials

	• Fullerenes and fibre-reinforced composite materials • Nanomaterials: Quantum Dots, hollow spheres and nanotubes . . . and other examples of advanced functional materials
Lern- und Qualifikationsziele	The students refresh and elaborate their knowledge on inorganic materials, materials chemistry as well as basic inorganic chemistry and solid state chemistry. This comprises fundamental aspects of the chemistry of the elements as well as state-ofthe- art knowledge on the synthesis, structure, properties (including optical properties) and application (including luminescence) of inorganic functional materials. The students • get familiar with basic inorganic chemistry and solid state chemistry • get familiar with concepts of describing crystal structures • know how to characterize inorganic solid compounds and materials • learn how to prepare inorganic compounds and solid materials • understand general aspects of structure-property relations • comprehend general concepts of solid state chemistry and inorganic functional materials • are able to rationalize fundamental properties of inorganic materials know general trends in view of a technical application of advanced inorganic materials
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.32 Module: Machine Vision [M-MACH-101923]

Modulcode	M-MACH-101923
Modultitel (deutsch)	2.32 Module: Machine Vision
Modultitel (englisch)	2.32 Module: Machine Vision
Modul-Verantwortliche/r	Dr. Martin Lauer (KIT) Prof. Dr.-Ing. Christoph Stiller (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 4 SWS
Leistungspunkte (ECTS credits)	8
Arbeitsaufwand (work load) in:	240 h
- Präsenzstunden	60 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	180 h
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 disussion of image convolution and typical filters for image enhancement concludes the chapter.

Edge and corner detection:

Gray level edges and gray level corners play an important role in machine vision since gray level edges often reveal valueable

information about the boundaries and shape of objects. Gray level corners can be used as feature points since they can be

identified easily in other images. This chapter introduces filters and algorithms to reveal gray level edges and gray level corners

like the Canny edge detector and the Harris corner detector.

Curve and parameter fitting:

In order to describe an image by means of geometric primitives (e.g. lines, circles, ellipses) instead of just pixels robust curve

and parameter fitting algorithms are necessary. The lecture introduces and discusses the Hough transform, total least sum of

squares parameter fitting as well as robust alternatives (M-estimators, least trimmed sum of squares, RANSAC)

Color processing:

The short chapter on color processing discusses the role of color information in machine vision and introduces various models

for color understanding and color representation. It concludes with the topic of color consistency.

Image Segmentation:

Image segmentation belongs to the core techniques of machine vision. The goal of image segmentation is to subdivide the

image into several areas. Each area shares common properties, i.e. similar color, similar hatching, or similar semantic

interpretation. Various ideas for image segmentation exist which can be used to create more or less complex algorithms. 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 classical measurement theory and enters the
	large field of artificial intelligence. Rather than just being developped and optimized by a programmer, the algorithms are
	adapting themselves to their specific task using training algorithms that are based on large collections of sample images.
	The chapter of pattern recognition introduces standard techniques of pattern recognition in the context of image understanding
	like the support vector machine (SVM), decision trees, ensemble and boosting techniques. It combines those classifiers with
	powerful feature representation techniques like the histogram of oriented gradients (HOG) features, locally binary patterns
	(LBP), and Haar features.
	Deep learning:
	Throughout recent years standard pattern recognition technqiues have more and more been outperformed by deep learning
	techniques. Deep learning is based on artificial neural networks, a very generic and powerful form of a classifier. The lecture
	introduces multi layer perceptrons as the most relevant form of artificial neural networks, discusses training algorithms and
	strategies to achieve powerful classifiers based on deep learning including deep auto encoders, convolutional networks, and
	multi task learning, among others.
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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	-
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

2.39 Module: Optical Engineering [M-ETIT-100456]

Modulcode	M-ETIT-100456
Modultitel (deutsch)	2.39 Module: Optical Engineering
Modultitel (englisch)	2.39 Module: Optical Engineering
Modul-Verantwortliche/r	Prof. Dr. Wilhelm Stork
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	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: I. Introduction (Optical Phenomena) II. Ray Optics (thin/thick lenses, principal planes, ABCD-matrices, chief rays, examples: Eye, IOL)

	III. Popular Applications (Magnifying glass, microscope, telescope, Time-of-flight) IV. Wave Optics (Interference, Diffraction, Spectrometers, LDV) V. Aberrations I (Coma, defocus, astigmatism, spherical aberration) VI. Fourier Optics (Periodical patterns, FFT spectrum, airy-patterns) VII. Aberration II (Seidel and Zernike Aberrations, MTF, PSF, Example: Eye) VIII. Fourier Optics II (Kirchhoff + Fresnel, contrast, example: Hubble-telescope) IX. Diffractive Optics Applications (Gratings, holography, IOL, CD/DVD/Blu-Ray-Player) X. Interference (Coherence, OCT) XI. Filters and Mirrors (Filters, antireflection, polarization, micro mirrors, DLPs) XII. Laser and Laser Safety (Laser principle, laser types, laser safety aspects) XIII. Displays (Pico projectors, LCD, LED, OLED, properties of displays)
Lern- und Qualifikationsziele	The students from different backgrounds refresh and elaborate their knowledge of engineering optics and photonics. They will get to know the basic principles of optical designs. They will connect these principles with real-world applications and learn about their problems and how to solve them. The students will know about the human view ability and the eye system. After the module they will be able to judge the basic qualities of an optical system by its quantitative data. After the course, students will: understand fundamental optical phenomena and apply it to solve optical engineering problems; work with the basic tools of optical engineering, i.e. ray-tracing by abcd-matrices; get a broad knowledge on real-world applications of optical engineering; learn about the potential of optical design for industrial, medical and day-to-day applications; know up-to-date optical engineering problems and its solutions.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Achievement will be examined in an oral examination (approx. 20 minutes).

Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- E. Hecht: Optics - J.W. Goodmann: Introduction to Fourier optics - K.K. Sharma: Optics - Principles and Applications
Unterrichtssprache	Englisch

2.40 Module: Optical Networks and Systems [M-ETIT-103270]

Modulcode	M-ETIT-103270
Modultitel (deutsch)	2.40 Module: Optical Networks and Systems
Modultitel (englisch)	2.40 Module: Optical Networks and Systems
Modul-Verantwortliche/r	Prof. Dr.-Ing. Sebastian Randel (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Photonic interconnects: rack-to-rack, board-to-board, chip-to-chip, datacenter interconnects, intensity modulation, direct

detection, single-mode fiber vs. multi-mode fiber, serial vs. parallel optics, space-division multiplexing vs. wavelength-division

multiplexing, Ethernet (10G, 40G, 100G), Fibre Channel, scaling and energy efficiency.

Access neetworks: fiber-to-the-X, passive optical networks (GPON, EPON, NG-PON2, WDM PON), statistical multiplexing vs.

point-to-point

Metro- and long-haul networks:

System-design aspects: dense WDM (ITU grid), optical amplifiers, chromatic dispersion, coherent detection, optical vs. |

	electronic impairment mitigation, capacity limits.
	Wavelength switching: wavelength selective switch (WSS), reconfigurable optical add-drop multiplexer (ROADM).
	Standards and protocols: synchronous optical networking and synchronous digital hierarchy (SONET/SDH), optical
	transport network (OTN), generalized multi-protocol label switching (GMPLS), software-defined networking (SDN).
	Optical networks in automotive and industrial automotion: polymer-optical fiber (POF), MOST Bus, Profibus and Profinet, optical
	vs. electrical communication links, overcoming bandwidth limitations using digital signal processing.
Lern- und Qualifikationsziele	The module provides knowledge about optical networks and systems with applications ranging from photonic interconnects, to
	fiber-to-the-home (FTTH), optical metro and long-haul networks, and automotive and industrial automation. The role of various
	network layers will be discussed in conjunction with relevant standards and protocols. Physical-layer specifications of relevant
	photonic components and system design trade-offs will be introduced.
	The students
	get familiar with optical network architectures and protocols
	learn how to design optical communication systems in a variety of application scenarios
	understand how application constraints (performance, cost, energy-efficiency) drive technology innovation
	comprehend the benefits and challenges of using optical communication compared to alternatives (e.g. electrical, and
	wireless)
	are familiar with relevant standardization bodies and are able to interpret essential aspects of standard documents.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	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.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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
Unterrichtssprache	Englisch

2.41 Module: Optical Systems in Medicine and Life Science [M-ETIT-103252]

Modulcode	M-ETIT-103252
Modultitel (deutsch)	2.41 Module: Optical Systems in Medicine and Life Science
Modultitel (englisch)	2.41 Module: Optical Systems in Medicine and Life Science
Modul-Verantwortliche/r	Prof. Dr. Werner Nahm (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	Optical Systems:
	Surgical microscope
	Scanning laser ophthalmoscope (SLO) / Confocal endomicroscope (CEM)
	Optical coherence tomography (OCT) / Optical biometer
	Refractive surgical laser
	Flow-Cytometry
	Applied Optical Technologies:
	Magnification and illumination
	Fluorescence and diffuse reflectance imaging
	Confocal laser microscopy

	Low coherence interferometry
	fs-Laser
	Laser scattering (Mie-Therory)
	Systems Design and Engineering:
	System architecture
	V-Model of Product Development Process
Lern- und Qualifikationsziele	Overall Course Objectives:
	This course will allow the students to understand how the basic optical and optoelectronic principles are applied in the design of
	modern medical devices and routine diagnostic equipment. Besides extending and deepening their expert knowledge
	in engineering sciences and physics this course will provide profound insight into the applicative, the regulatory and safety and
	the cost requirements. This will help to be able to understand how the systems are designed to fulfill the requirements.
	Furthermore, in this course the students will be introduced into case-based learning. The in-class journal club helps to make the
	students become more familiar with the advanced literature in the field of study. This interactive format helps to improve
	the students' skills of understanding and debating current topics of active interest.
	Teaching Targets:
	The successful participation in this course enables the students to
	derive and formulate system requirements
	layout the system architecture of optical devices
	explain the underlying physical and physiological principles and mechanisms
	elaborate technical and methodological constraints and limitations
	present, challenge and debate recent research results
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	60 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- M. Kaschke, Optical Devices in Opthalmology and Optometry, Willey-VCH
Unterrichtssprache	Englisch

2.42 Module: Optical Transmitters and Receivers [M-ETIT-100436]

Modulcode	M-ETIT-100436
Modultitel (deutsch)	2.42 Module: Optical Transmitters and Receivers
Modultitel (englisch)	2.42 Module: Optical Transmitters and Receivers
Modul-Verantwortliche/r	Prof. Dr. Wolfgang Freude (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	135 h
Inhalte	The course concentrates on basic optical communication concepts and connects them with the properties of physical components. The following topics are discussed: Advantages and limitations of optical communication systems Optical transmitters comprising lasers and modulators Optical receivers comprising direct and heterodyne reception Characterization of signal quality
Lern- und Qualifikationsziele	The students understand the peculiarities of optical communications, and how optical signals are generated, transmitted and received, know about sampling, quantization and coding,

	learn the basics about noise on reception,
	understand the properties of a linear and a nonlinear optical fibre channel,grasp the idea of channel capacity and
	spectral efficiency,
	know about various forms of modulation,
	acquire knowledge of optical transmitter elements,
	understand the function of optical amplifiers,
	have a basic understanding of optical receivers,
	know the sensitivity limits of optical systems, and
	understand how these limits are measured.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral examination (approx. 20 minutes). The individual dates for the oral examination are offered regularly.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.43 Module: Optical Waveguides and Fibers [M-ETIT-100506]

Modulcode	M-ETIT-100506
Modultitel (deutsch)	2.43 Module: Optical Waveguides and Fibers
Modultitel (englisch)	2.43 Module: Optical Waveguides and Fibers
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Tutorium 1 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	75 h
Inhalte	Introduction: Optical communications
	Fundamentals of wave propagation in optics: Maxwell´s equations in optical media, wave equation and plane waves,
	material dispersion, Kramers-Kroig relation and Sellmeier equations, Lorentz and Drude model of refractive index, signal
	propagation in dispersive media.
	Slab waveguides: Reflection from a plane dielectric boundary, slab waveguide eigenmodes, radiation modes, inter- and
	intramodal dispersion, metal-dielectric structures and surface plasmon polariton propagation.
	Planar integrated waveguides: Basic structures of integrated optical waveguides, guided modes of rectangular

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waveguides (Marcatili method and effective-index method), basics of numerical methods for mode calculations (finite

difference- and finite-element methods), waveguide technologies in integrated optics and associated fabrication methods

Optical fibers: Optical fiber basics, step-index fibers (hybrid modes and LP-modes), graded-index fibers (infinitely

extended parabolic profile), microstructured fibers and photonic-crystal fibers, fiber technologies and fabrication

methods, signal propagation in single-mode fibers, fiber attenuation, dispersion and dispersion compensation

Waveguide-based devices: Modeling of dielectric waveguide structures using mode expansion and orthogonality

relatons, multimode interference couplers and directional couplers, waveguide gratings, material gain and absorption in

optical waveguides, bent waveguides

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Lern- und Qualifikationsziele

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The students

conceive the basic principles of light-matter-interaction and wave propagation in dielectric media and can explain the

origin and the implications of the Lorentz model and of Kramers-Kronig relation,

are able to quantitatively analyze the dispersive properties of optical media using Sellmeier relations and scientific

databases,

can explain and mathematically describe the working principle of an optical slab waveguide and the formation of guided

modes,

are able to program a mode solver for a slab waveguide in Matlab,

are familiar with the basic principle of surface plasmon polariton propagation,

know basic structures of planar integrated waveguides and are able to model special cases with semi-analytical

approximations such as the Marcatili method or the effective-index method,

are familiar with the basic concepts of numerical mode solvers and the associated limitations,

are familiar with state-of-the-art waveguide technologies in integrated optics and the associated fabrication methods,

know basic concepts of of step-index fibers, graded-index fibers and microstructured fibers,

are able to derive and solve basic relations for step-index fibers from Maxwell's equations,

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	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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: Oral exam Duration of Examination: approx. 20 minutes Modality of Exam: The written exam is offered continuously upon individual appointment.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.48 Module: Photonic Integrated Circuit Design and Applications [METIT-105914]

Modulcode	METIT-105914
Modultitel (deutsch)	2.48 Module: Photonic Integrated Circuit Design and Applications
Modultitel (englisch)	2.48 Module: Photonic Integrated Circuit Design and Applications
Modul-Verantwortliche/r	Prof. Dr.-Ing. Christian Koos (KIT) Prof. Dr.-Ing. Sebastian Randel (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each summer term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture inclusive Exercise class 2 SWS In addition to the teaching of fundamental concepts to the extent necessary to enable students to perform practical designs, the lecture will focus from the start on a specific technology platform (silicon-on-insulator) in which the students will solve design problems of increasing complexity with the design suite Lumerical. As the final hands-on problem, students will design an entire photonic subsystem for an application of their choice, leaving free room for creative thinking and self-driven work. Since each group of students will present one of the solved designed problems to their peers, students will get exposed to solutions found for and practical problems encountered in a variety of design tasks, providing them with a wider experience base to draw on for future design. Since the class will be taught by lecturers from several Universities, all lectures will be streamed live (with the possibility to interact and to ask questions) and made available online. Design tasks will be performed with the Design Suite Lumerical, for which introductory videos will be made available. An online forum will be provided to allow students to ask questions offline to

	the lecturers as well as to interact with each other, inside and across Universities.
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in: - Präsenzstunden - Selbststudium (einschl. Prüfungsvorbereitungen)	180 h 30 h 150 h
Inhalte	Lectures: Lecture 1: Introduction to silicon photonics Lecture 2: Silicon photonics – technology overview Lecture 3: Wave propagation in silicon photonic waveguides Lecture 4: Mode expansion and orthogonality Lecture 5: Coupled-mode theory Lecture 6: Selected passive devices Lecture 7: Modulators Lecture 8: Photodetectors Lecture 9: Optical amplifiers and lasers Lecture 10: Test and packaging Lecture 11: Optical communications Lecture 12: Optical metrology Lecture 13: Biophotonics and neurophotonics Lecture 14: Integrated quantum optics and optical computing Design lab: Problem Set 1: Mode fields and mode expansion Problem Set 2: Coupling efficiency and coupled-mode theory Design Project A: Optical filter Design Project B: Optical transceiver Design Project C: Optical communication link
Lern- und Qualifikationsziele	The students understand the basic principles of photonic component design and can apply them to concrete design tasks of increasing complexity and independence, that they will solve in small groups and present to their peers. Doing so they will learn to translate theoretical knowledge gained during the lecture into actionable knowledge used to solve hands-on design tasks. In addition to design principles, students will learn how to satisfy key requirements for making photonic integrated circuits

	manufacturable and useable in a system environment, such as corner analysis of manufacturing tolerances, design for
	testability, design for manufacturability, and packaging. In short, we aim at teaching students the skills for hands-on design of
	manufacturable and application relevant photonic integrated circuits, preparing them to productively contribute to a design team.
	In addition, we will convey the most recent trends in the application of photonic integrated circuits and let students design a
	circuit addressing one of these application spaces, giving them a feeling for both the potential as well as the limitations of the
	technology, so that they may take informed decisions on what systems to integrate in the future.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Part 1 – Solutions of problem sets: We will grade your solutions of the various problem sets and design projects. To this
	end, please upload your solution via the online teaching platform of your respective institution (see above) before the
	respective deadline. Please merge all pages into a single pdf file, and please use a scanner. Smartphone made
	snapshots are often illegible, and in this case your solutions cannot not be evaluated. In case there are any technical
	difficulties with the platforms, you may also submit your solutions by e-mail to picda@ipq.kit.edu before the respective
	deadline.
	Part 2 - Presentation of one pre-assigned problem set: At the beginning of the term, design projects will be pre-assigned
	to groups of participants. Each of these groups will explain their approach and results to lecturers and peer students in a
	short presentation (approx. 15 min), followed by approx. 10 min of public discussion with peer students and professors,
	and an individual private interview of each group member (approx. 10 min per person).
	The overall impression is rated.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	-
Unterrichtssprache	Englisch

2.50 Module: Quantum Optics [M-PHYS-103093]

Modulcode	M-PHYS-103093
Modultitel (deutsch)	2.50 Module: Quantum Optics
Modultitel (englisch)	2.50 Module: Quantum Optics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 4 SWS + Exercise class 2 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	90 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	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	The students of quantum optics comprehend the physics of quantum optical phenomena, the necessary theoretical means for
	their description, and the application of quantum optical resources in different applications and technologies. They learn how to
	express quantum optical phenomena in a mathematical language and can apply routinely different techniques to study quantum
	optical phenomena in specific situations. They are trained to solve basic problems in quantum optics.
	The students
	learn about the quantisation of electromagnetic fields,
	understands the details of different quantum states of light,
	get an overview over experiments that were important in the development of quantum optics,
	develop an understanding for the quantum optical description of the first and second order coherence functions, and
	understand and can routinely apply different means to describe the interaction of quantum states of light with quantum
	emitters.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.55 Module: Solar Energy [M-ETIT-100524]

Modulcode	M-ETIT-100524
Modultitel (deutsch)	2.55 Module: Solar Energy
Modultitel (englisch)	2.55 Module: Solar Energy
Modul-Verantwortliche/r	Prof. Dr. Bryce Sydney Richards (KIT)
Voraussetzung für die Zulassung zum Modul	None
Empfohlene bzw. erwartete Vorkenntnisse	none
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 3 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	60 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	120 h
Inhalte	I. Introduction: The Sun

II. Semiconductor fundamentals

III. Solar cell working principle

IV. First Generation solar cells: silicon wafer based

V. Second Generation solar cells: thin films of amorphous silicon, copper indium gallium diselenide, cadmium telluride,

organic photovoltaics and dye sensitized solar cells

V. Third Generation Photovoltaics: high-efficiency device concepts incl. tandem solar cells

VI. Modules and system integration

VII. Cell and module characterization techniques |

	VIII. Economics, energy pay-back time, environmental impact IX. Other solar energy harvesting processes, incl. thermal and solar fuels X. Excursion
Lern- und Qualifikationsziele	The students: • understand the basic working principle of pn-junction solar cells, • learn about the different kinds of solar cells (crystalline and amorphous silicon, CIGS, Cadmium telluride, organic, dyesensitized solar cells, etc.), • get an overview over upcoming third-generation photovoltaic concepts, • receive information on photovoltaic modules and module fabrication, • develop an understanding of solar cell integration and feeding the electrical power to the grid, • get insight into solar concentration and tandem solar cells for highly efficient energy conversion, • compare photovoltaic energy harvesting with solar thermal technologies • understand the environmental impact of solar energy technologies. Die Studentinnen und Studenten können in englischer Fachsprache sehr gut kommunizieren.
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Type of Examination: written exam Duration of Examination: 120 Minutes Modality of Exam: One written exam at the end of each semester.
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- P. Würfel: Physics of Solar Cells - V. Quaschning: Renewable Energy Systems - C. Honsberg and S. Bowden, PV Education CD-ROM and website, http://www.pveducation.org/pvcdrom
Unterrichtssprache	Englisch

2.56 Module: Solar Thermal Energy Systems [M-MACH-101924]

Modulcode	M-MACH-101924
Modultitel (deutsch)	2.56 Module: Solar Thermal Energy Systems
Modultitel (englisch)	2.56 Module: Solar Thermal Energy Systems
Modul-Verantwortliche/r	apl. Prof. Dr. Ron Dagan (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each winter term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture + tutorial 2 SWS
Leistungspunkte (ECTS credits)	4
Arbeitsaufwand (work load) in:	120 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	90 h
Inhalte	I. Introduction to solar energy: Energy resources, consumption and costs
	II. The sun as an energy resource:
	Structure of the sun, Black body radiation, solar constant, solar spectral distribution
	Sun-Earth geometrical relationship
	III. Passive and active solar thermal applications.
	IV. Fundamentals of thermodynamics and heat transfer
	V. Solar thermal systems - solar collector-types, concentrating collectors, solar towers. Heat losses and efficiency
	VII. 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.
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 Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	oral exam of about 30 minutes
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- Foster, Ghassemi, cota,; Solar Energy - Duffie and Beckman; Solar engineering of thermal processes - Holman:, Heat transfer - Heinzel; script to solar thermal energy (in German)
Unterrichtssprache	Englisch

2.58 Module: Spectroscopic Methods [M-CHEMBIO-101900]

Modulcode	M-CHEMBIO-101901
Modultitel (deutsch)	2.58 Module: Spectroscopic Methods
Modultitel (englisch)	2.58 Module: Spectroscopic Methods
Modul-Verantwortliche/r	Prof. Dr. Manfred Kappes (KIT) apl. Prof. Dr. Andreas-Neil Unterreiner (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	einmalig
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	I. Introduction to electronic spectroscopy (Born Oppenheimer approximation, Franck-Condon factor, relaxation processes) II. 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) III. 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)

	IV. Introduction to time-dependent phenomenon including time-dependent perturbation theory for selection rules, spectral line shape V. Generation and characterization of tunable laser pulses with pulse durations well below 1 picosecond VI. Various methods of pump-probe spectroscopy covering the spectral range from the microwave to the X-ray regime
Lern- und Qualifikationsziele	The students get introduced into various methodologies of molecular spectroscopy in frequency and time domain. Due to different basic knowledge they first get acquainted with the microscopic physical background, but later on with the interpretation of the respective optical spectra and application in various fields. The students enhance their knowledge on spectroscopic equipment and optical components for the respective spectroscopic and/or microscopic technique. The students • know the quantum mechanical basis of molecular rotational, vibrational and electronic spectroscopy • conceive a microscopic understanding of optical excitation/deexcitation processes in molecules, i.e. light-matter interaction • understand the interplay between spectroscopic method, experimental design and required optical components • are familiar with sample preparation techniques in molecular spectroscopy (supersonic expansion, ion traps, soft-landing on surfaces, matrix-isolation) • learn time scales of various molecular motions (especially rotation and vibration) before and during chemical/biochemical reactions • will get in touch with timescales and frequencies of molecular properties and experience their interconnection are introduced into linear and nonlinear molecular spectroscopy including two-dimensional techniques such as two-dimensional vibrational spectroscopy)
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-

Empfohlene Literatur	- Demtröder: Laser Spectroscopy, Rullière: Femtosecond Laser Pulses, Atkins: Molecular Quantum - Mechanics, various review articles
Unterrichtssprache	Englisch

2.60 Module: Theoretical Nanooptics [M-PHYS-102295]

Modulcode	M-PHYS-102295
Modultitel (deutsch)	2.60 Module: Theoretical Nanooptics
Modultitel (englisch)	2.60 Module: Theoretical Nanooptics
Modul-Verantwortliche/r	Prof. Dr. Carsten Rockstuhl (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	irregular
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS + Exercise class 1 SWS
Leistungspunkte (ECTS credits)	6
Arbeitsaufwand (work load) in:	180 h
- Präsenzstunden	45 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	135 h
Inhalte	Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections. Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates. Properties of plasmonic nanoparticles and the ability to tune their properties Notion of optical antennas and the discussion of their basic characteristics Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays.

	Discussion of metamaterials (unit cells, homogenization, light propagation, applications)
	Transformation optics
	Analytical modeling and phenomenological tools to describe nanooptical systems
Lern- und Qualifikationsziele	The students
	understand dispersion relations for light propagation in various optical systems
	can describe light interaction with isolated objects and plasmonic nanoparticles
	are familiar with optical antennas and their fundamental properties
	can apply coupled mode theory to waveguide arrays
	understand metamaterials, transformation optics, and analytical modeling techniques for nanooptical systems
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	Oral Exam. The total duration of the oral exam is approx. 60 minutes
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- 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

2.62 Module: X-Ray Optics [M-MACH-101920]

Modulcode	M-MACH-101920
Modultitel (deutsch)	2.62 Module: X-Ray Optics
Modultitel (englisch)	2.62 Module: X-Ray Optics
Modul-Verantwortliche/r	Dr. Arndt Last (KIT)
Voraussetzung für die Zulassung zum Modul	
Empfohlene bzw. erwartete Vorkenntnisse	
Art des Moduls (Pflicht-, Wahlpflicht- oder Wahlmodul)	MSc. Photon Science and Technology: Required Elective Course Specialization
Häufigkeit des Angebots (Modulturnus)	Each term
Dauer des Moduls	1 term
Zusammensetzung des Moduls / Lehrformen (V, Ü, S, Praktikum, …)	Lecture 2 SWS
Leistungspunkte (ECTS credits)	3
Arbeitsaufwand (work load) in:	90 h
- Präsenzstunden	30 h
- Selbststudium (einschl. Prüfungsvorbereitungen)	60 h
Inhalte	I. Introduction: Application of X-ray optics II. X-ray generation III. Propagation of X-rays in matter IV. X-ray detection V. Types of X-ray optics: reflecting, refracting, diffracting, absorbing VI. Characteristics of X-ray optics VII. Methods to simulate X-ray optics (ray tracing, wave propagation) VIII. Manufacturing of X-ray optics IX. Characterization of X-ray optics
Lern- und Qualifikationsziele	The students

	know the importance of X-ray optics in science and material analysis
	can describe the basic phenomena of X-ray generation, propagation and detection
	can calculate the optical path X-rays will follow
	are familiar with different types of X-ray optics
	can decide what X-ray optical component is suited best for what application
	comprehend the concepts of refraction, reflection, diffraction and absorption and are aware of their importance in X-ray
	optics
	know the differences between ray tracing and wave propagation methods and can assess what method is applicable in
	what case
	conceive manufacturing methods of X-ray optics
	know how to characterize X-ray optical components
Voraussetzung für die Zulassung zur Modulprüfung	-
Voraussetzung für die Vergabe von Leistungspunkten (Prüfungsform)	90 min written exam
Zusätzliche Informationen zum Modul	-
Empfohlene Literatur	- A. Erko, M. Idir, Th. Krist and A. G. Michette (editors), Modern Developments in X-Ray and Neutron Optics
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
PR	Klausur/Prüfung
K	Kolloquium
K/P	Kolloquium/Praktikum
KS	Konferenz/Symposium
kV	Kulturelle Veranstaltung
Ku	Kurs
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
PrVo	Prüfungsvorbereitung
QB	Querschnittsbereich
RE	Repetitorium
V/R	Ringvorlesung
SU	Schulung
S	Seminar
S/E	Seminar/Exkursion
S/Ü	Seminar/Übung
SZ	Servicezeit
SI	Sitzung
SoSch .	Sommerschule
SO	Sonstiges
SV	Sonstige Veranstaltung
SK	Sprachkurs
TG	Tagung
TT	Teleteaching
TN	Treffen

Tu........	Tutorium		SQ.......	Schlüsselqualifikationen
T..........	Tutorium		SS	Sommersemester
Ü	Übung		SWS ...	Semesterwochenstunden
Ü/B	Übung/Blockveranstaltung		TE	Teilnahme
Ü	Übungen		TP	Thesenpublikation
Ü/I	Übung/Interdisziplinär		ThULB	Thüringer Universitäts- und Landesbibliothek
Ü/P	Übung/Praktikum			
Ü/T	Übung/Tutorium		VVZ.....	Vorlesungsverzeichnis
Ve........	Versammlung		WS	Wintersemester
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 abbrevations

Anm.....	Anmerkung
ASQ	Allgemeine Schlüsselqualifikationen
AT	Altes Testament
E..........	Essay
FSQ.....	Fachspezifische Schlüsselqualifikationen
FSV.....	Fakultät für Sozial- und Verhaltenswissenschaften
GK.......	Grundkurs
IAW	Institut für Altertumswissenschaften
LP........	Leistungspunkte
NT	Neues Testament