Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science Advanced Optical Technologies

(Version of examination regulation: 20222)

Table of contents

1	**Module name** 42105	**Basics of Laser**	**5 ECTS**
2	Courses / lectures	Praktikum: Basic of Lasers - Lab sessions (0 SWS) Vorlesung mit Übung: Basics of Laser (4 SWS)	- 5 ECTS
3	Lecturers		

4	**Module coordinator**	Prof. Dr. Nicolas Joly
5	**Contents**	Laser technology developed enormously since its first demonstration in 1960. Although at that time laser was described as "a solution in search of a problem it is nowadays used everywhere, from high-precision spectroscopy to bar-scanner in supermarkets, from eye-surgery to metal welding for car industry. The lecture focuses on the basics of laser and serves as a first glance in the fascinating world of coherent light sources. It reviews four major aspects of lasers: (i) the description of the active material, which provides the gain for the system (ii) the laser cavity, which defines the spatial structure of the laser beam (iii) the propagation of laser beam using the ABCD matrices formalism and (iv) the different dynamical regimes of laser, in particular the way to generate pulses. Besides the lecture/exercises the students are invited to test the concepts seen during the lecture on two laser systems: a solid-state Nd:YAG laser and a Er-doped fibre laser.
6	**Learning objectives and skills**	Students will be able to: Describe the active material using the rate equations Check the stability of a laser cavity and extract the beam parameters from the physical parameters of the cavity (length, radius of curvature of the mirrors etc.) Use ABCD matrix to define the spatial properties of a laser beam and shape the beam (focusing, coupling etc.) Align a laser cavity and observe the different spatial modes that can be generated Understand the different dynamical behaviours of a laser (mode-locked laser, Q-switch laser, continuous).
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Practical achievement Written examination (90 minutes)
11	**Grading procedure**	Practical achievement (20%) Written examination (80%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h

14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	"Laser by A.E. Siegman, University Science book, 1986 "Handbook of Lasers and Optics by F. Träger, Springer, 2007 "Les lasers by D.Dangoisse, D. Hennequin and V. Zehnlé)Dhaoui, Dunod 1998 "Principles of Lasers, 5th ed. by Orazio Svelto, Springer 2010

1	**Module name** 42101	**Fundamentals of Optics**	**15 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Fundamentals of Optics (10 SWS)	15 ECTS
3	Lecturers	Prof. Dr. Vahid Sandoghdar Dr. Hannieh Fattahi Dr. Johannes Knorr	

4	**Module coordinator**	Dr. Hannieh Fattahi Prof. Dr. Vahid Sandoghdar
5	**Contents**	*Optic and quantum phenomenons* *- Light as a wave* Wave nature of light, Maxwell equation, plan waves, spherical waves, monochromatic fields *-Light and matter* Light scattering, wave propagation, polarization and current density, modified Maxwell equations, modified wave equation, law of refraction, Fresnel equations, Brewster angle, total reflection, polarization of material *- Geometrical optics* Ray optics, ray transfer matrix analysis, principal planes, aberrations, optical resonators *-Diffraction and interferenz* HuygensFresnel principle, Fraunhofer diffraction, microscopes, telescopes, resolution limit, imaging techniques, humand eye, polarization of electromagnetic fields, plain waves in homogenous material, birefringence, polarized elements *-Basic experiment in quantum phenomenons * Particle characteristics of light, photoelectric effect, black-body radiation, compton effect, wave nature of particles, wave nature of electrons *-Basic equations of quantum mechanics* Schrödinger equation, time-independent Schrödinger equation, wave function, particle in a box, tunnel effect *-Specialization* Advanced Molecular Spectroscopy
6	**Learning objectives and skills**	Students should be able • to describe and explain the experimental basics and the mathematical description of optic and quantum phenomena • apply laws of physics and mathematical methods to actual problems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (150 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester

13	**Workload in clock hours**	Contact hours: 150 h Independent study: 300 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	no Bibliography information available!

1	**Module name** 1996	**Internship (M.Sc. Advanced Optical Technologies 20222)** no english module name available for this module	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Dr. Jürgen Grossmann
5	**Contents**	Students do an internship of five weeks full time (or an equivalent time part time) at an institute of the university, at another research institute or in the industry.
6	**Learning objectives and skills**	During the internship students learn how to work in an organisation in the field of optical technologies.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	every semester
13	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	no Bibliography information available!

1	**Module name** 42110	**Numerical Methods and Topics in Optical Technologies**	**5 ECTS**
2	Courses / lectures	Sonstige Lehrveranstaltung: Topics of Optical Technologies (2 SWS) Übung: Numerical tools in optics (Matlab) (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Silvana Burger Prof. Dr. Nicolas Joly Prof. Dr. Christoph Pflaum Prof. Dr. Maria Chekhova Prof. Dr.-Ing. Bernhard Schmauß Dr.-Ing. Florian Klämpfl Dr.-Ing. Michael Rausch Dr. Angela Perez Castaneda	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	The module introduces the topics which can be chosen as major topics in the second and third semester of MAOT and the use of the software Matlab (or another numerical tool for the analysis of data).
6	**Learning objectives and skills**	Students • do understand the basic concept of Matlab • do know the basic functions of Matlab • are able to apply Matlab for solving numerical problems in the field of optics • know different application fields of optical technologies • are able to decide about their major topics for the second and third term
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	no Bibliography information available!

1	**Module name** 1994	**Project report (M.Sc. Advanced Optical Technologies 20222)** no english module name available for this module	**10 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	The student have to write a project report under the supervision of a professor of the university. It should preferably be written in one of the major topics of the student.
6	**Learning objectives and skills**	The module prepares for writing a more comprehensive report in the module M16 Master's Thesis.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 3
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written assignment
11	**Grading procedure**	Written assignment (100%)
12	**Module frequency**	Unregelmäßig
13	**Workload in clock hours**	Contact hours: 0 h Independent study: 300 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	
16	**Bibliography**	no Bibliography information available!

Optical Metrology

1	**Module name** 67112	**Advanced microscopic techniques** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Hauptseminar: Advanced Microscopic Techniques (0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Vahid Sandoghdar Kanwarpal Singh	

4	**Module coordinator**	Prof. Dr. Vahid Sandoghdar
5	**Contents**	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 non linear 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.
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 46228	**Glas I** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Neuer Master: WS-Vibrational spectroscopies, from theory to practice (2 SWS) Vorlesung mit Übung: Neuer Master: WS-Optical properties of glasses (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Dominique Ligny	

4	**Module coordinator**	Prof. Dr. Dominique Ligny
5	**Contents**	|Optical properties of glasses| • Fundamental concepts: The electromagnetic spectrum and units, Absorption, Luminescence, Scattering • Optical transparency of solids: Optical magnitudes and the dielectric constant, The Lorentz Oscillator, Metals, Semiconductors and insulators, Excitons, Reflection and polarization • Optical glasses: Optical aberration and solutions, Dispersion properties and composition • Colors in glasses: The eye, Optically Active Centers, Transition metals in glasses, Metallic and Chalcogenide nanoparticles • Chromism: Thermochromism, Photochromism, Gasochromism, Electrochromism • IR glasses: Chalcogenide, Fluorite glasses • Optical Fibers: Principle, Manufacturing, Applications, Photonic fibers |Vibrational spectroscopies, from theory to practice | • Nature of vibrations inside matter • Interaction light matter • Instrumentation • Raman application • Infrared Spectroscopy • Advanced technics
6	**Learning objectives and skills**	|Spectroscopy techniques applied to amorphous materials | The students will • Understand the solid state physic background link to the optical properties of all type of materials • Be able to explain the different ways to create colors • Choose the appropriate glass compositions to realize optical device in the infrared region • Have an overview of the different technologies link to light management • Know the different parameters that define an Optical glass fiber and choose them in regard of the attended application |Vibrational spectroscopies, from theory to practice| The student will • Understand in a comprehensive way the solid state physic background link to these spectroscopies

		• Know the different parts of a spectrometer and their characteristic parameter • Exercise himself to set the parameters of an observation and run the measurements • Treat the data by applying the needed corrections • Evaluate the data using peak fitting, momentum calculations and Principal Component Analysis • Deduce information on the structure of common glasses
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 582360	**Modern Optics 2: Nonlinear Optics** Nonlinear optics	**5 ECTS**
2	Courses / lectures	Vorlesung: Modern Optics 2: Nonlinear Optics (2 SWS)	-
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Maria Chekhova	

4	**Module coordinator**	Prof. Dr. Nicolas Joly
5	**Contents**	*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.
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	*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)

1	**Module name** 67009	**Novel techniques in ultrafast spectroscopy** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Novel techniques in ultrafast spectroscopy (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Daniele Fausti Dr. Francesca Fassioli Olsen	

4	**Module coordinator**	Prof. Dr. Daniele Fausti
5	**Contents**	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/
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!

9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (45 minutes)
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Primary literature will be provided by the supervisors of the individual topics.

1	**Module name** 42935	**Optical diagnostics in energy and process engineering** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Optical Diagnostics in Energy and Process Engineering (2 SWS) Übung: Exercise in Optical Diagnostics in Energy and Process Engineering (2 SWS)	5 ECTS -
3	Lecturers	Dr.-Ing. Franz Huber Prof. Dr.-Ing. Stefan Will	

4	**Module coordinator**	Simon Aßmann Dr.-Ing. Franz Huber Prof. Dr.-Ing. Stefan Will
5	**Contents**	**Introduction to conventional and novel optical techniques to measure state and process functions in thermodynamical systems:** • Properties of light; properties of molecules; Boltzmann distribution • Geometric optics and optical devices • Lasers (HeNe, Nd:YAG, dye, frequency conversion); continuous wave and pulsed lasers • Photoelectric effect; photodetectors (photomultiplier, photodiode, CCD, CMOS, image intensifier); digital image processing; image noise and resolution • Shadowgraphy and Schlieren techniques (flow and mixing) • Elastic light scattering (Mie scattering, Rayleigh thermometry, nanoparticle size and shape, droplet sizing) • Raman scattering (species concentration, temperature, diffusion) • Incandescence (thermal radiation, temperature fields, pyrometry, particle sizing) • Velocimetry (flow fields, velocity) • Absorption (temperature, pressure, species, concentration) • Fluorescence and phosphorescence (temperature, species, concentration)
6	**Learning objectives and skills**	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
7	**Prerequisites**	Basics in thermodynamics and fluid mechanics. Students of other subjects (Chemical- and Bioengineering, Mechanical Engineering, Life Science Engineering, Energy Technology, Computational Engineering) can participate.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• Lecture Slides • Bräuer, Andreas: In situ Spectroscopic Techniques at High Pressure, Amsterdam 2015

1	**Module name** 45730	**Optical Technologies in Life Science** Optical technologies in life science	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Optical Technologies in Life Science (4 SWS)	5 ECTS
3	Lecturers	Lucas Kreiß Prof.Dr.Dr. Oliver Friedrich PD Dr.habil. Sebastian Schürmann Prof. Dr. Maximilian Waldner	

4	**Module coordinator**	PD Dr.habil. Sebastian Schürmann
5	**Contents**	Inhalte • Anwendungen optischer Messmethoden im Bereich der Zellbiologie und Medizin • Mikroskopie: Grundlegende Konzepte und Kontrastverfahren, Auflösungsvermögen und Grenzen, Aufbau und Komponenten von Lichtmikroskopen, Fluoreszenz-Mikroskopie • Anwendungen von Fluoreszenz-Mikroskopie im Life Science Bereich, Verfahren zur Markierung biologischer Strukturen und Vorgänge in Zellen • Epifluoreszenz-, Konfokal-, Multiphotonen-Mikroskopie, Konzepte und Anwendungsbeispiele • Optische Endoskopie und Endomikroskopie in Forschung und Klinik • Super-Resolution Mikroskopie, Konzepte und Anwendungsbeispiele für optische Bildgebung jenseits der beugungsbedingten Auflösungsgrenze 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
6	**Learning objectives and skills**	Lernziele und Kompetenzen Die Studierenden • verstehen die grundlegenden Konzepte und technische Umsetzung optischer Technologien im Bereich Life Sciences und kennen typische Anwendungsbeispiele

		• können verschiedene technische Ansätze im Hinblick auf wissenschaftlich Fragestellungen vergleichen und bewerten • können Vor- und Nachteile verschiedener Technologien, sowie konzeptionelle und praktische Limitationen einschätzen und bei der Analyse wissenschaftlicher Ansätze und Ergebnisse berücksichtigen • können selbstständig vertiefende Informationen zu technischen Lösungen, Materialien und Methoden im Bereich der Mikroskopie und Spektroskopie sammeln, strukturieren, und für die zielgerichtete Planung wissenschaftlicher Experimente auswählen • können wissenschaftliche Fragestellungen und technische Ansätze in Kleingruppen kritisch diskutieren und gemeinschaftlich Ansätze zur Beantwortung von Forschungsfragen mit Hilfe optischer Technologien entwickeln Learning objectives and competences: 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.
7	**Prerequisites**	• Grundkenntnisse im Bereich Optik und Zellbiologie • Basic knowledge in the fields of optics and cell biology is required
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester

16	**Teaching and examination language**	english
17	**Bibliography**	• 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.

1	**Module name** 45370	**Produktanalyse** Product analysis	**5 ECTS**
2	Courses / lectures	Übung: Übung Produktanalyse (1 SWS) Vorlesung: Produktanalyse (2 SWS)	- 4 ECTS
3	Lecturers	Dr.-Ing. Johannes Walter Prof. Dr.-Ing. Wolfgang Peukert	

4	**Module coordinator**	Dr.-Ing. Johannes Walter
5	**Contents**	The module introduces modern (optical) techniques for characterization of disperse systems in chemical engineering and materials science. The participants will learn general principles as well as where, when and on which time scale information on materials properties can be gained by the discussed methods. For disperse systems the latter can be for example particle size, particle shape, materials composition, electronic properties and surface chemistry as well as surface charge. • Introduction to Materials Properties and Classification • Sampling, Error Sources and their Analysis • Definition and Determination of Particle Distribution, Size and Shape • Principles Optics and Diffraction I • Principles Optics and Diffraction II • Diffraction, Rayleigh-, Mie scattering • Static and Dynamic Light scattering • X-Ray Scattering and Applications • Zetapotential and its measurement with optical methods • Analytical Ultra-Centrifugation with Multi-Wavelength Optics • Nonlinear Optics at Interfaces and its Application • Color and its Measurement: UV-Vis and Fluorescence Spectroscopy • Infrared and Raman Spectroscopy including Surface-Enhanced Techniques • Scanning Mobility Particle Sizer (SMPS) • Scanning Probe Microscopy and Electron Microscopy
6	**Learning objectives and skills**	• The participants will learn about the fundamentals of light-matter interactions and acquire the necessary skills to understand the working principles of the discussed experimental methods. • The participants will learn which material property is accessible by the discussed methods for product analysis as well as where and when each method can be applied. • The participants will learn on how to judge the results of an individual measurement technique and will learn about its inherent boundaries (e.g. resolution etc.) • The participants will learn where a combination of several techniques is more promising.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	• Principles of physics extended (9. ed., internat. student version); Authors: David Halliday, Robert Resnik, Jearl Walker; Wiley 2011 • Springer Handbook of Materials Measurement Methods; Authors: Horst Czichos, T. Saito, Smith Leslie; Springer 2006 (electronic access within FAU) • Nonlinear Optics; Author: Robert W. Boyd; Academic Press 2008

1	**Module name** 44960	**Thermophysikalische Eigenschaften von Arbeitsstoffen der Verfahrens- und Energietechnik** Thermophysical properties of working materials in process and energy engineering	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Thermophysikalische Eigenschaften von Arbeitsstoffen der Verfahrens- und Energietechnik (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Thomas Manfred Koller Dr.-Ing. Tobias Klein Dr.-Ing. Michael Rausch Prof. Dr.-Ing. Andreas Paul Fröba Dr. Johannes Knorr	

4	**Module coordinator**	Dr.-Ing. Thomas Manfred Koller
5	**Contents**	• Bedeutung von Stoffdaten in der Verfahrens- und Energietechnik • Gleichgewichtseigenschaften zur Charakterisierung von Arbeitsstoffen, z.B. in Form der thermodynamischen Zustandseigenschaften und -größen Dichte, innere Energie, Enthalpie, Entropie, spezifische Wärmekapazität, Schallgeschwindigkeit, Brechungsindex, Oberflächen- und Grenzflächenspannung • Transporteigenschaften zur Charakterisierung des molekularen Masse-, Energie- und Impulstransportes, z.B. Viskosität, Diffusionskoeffizient, Soret-Koeffizient, Thermodiffusionskoeffizient, Wärme- und Temperaturleitfähigkeit • Anwendungsbezogene Stoffdatenrecherche in der wissenschaftlichen Literatur, Tabellenwerken und Datenbanken • Korrelationen und Vorhersagemethoden für Stoffeigenschaften • Methoden zur experimentellen Bestimmung und prozessbegleitenden Messung von Stoffdaten, insbesondere durch moderne laseroptische Techniken • Grundzüge der theoretischen Bestimmung von Stoffdaten mit Hilfe der molekularen Modellierung • Aufstellung von thermischen und kalorischen Zustandsgleichungen *Content* • The importance of thermophysical properties in process and energy engineering • Equilibrium properties for the characterization of working materials, e.g., in the form of thermodynamic properties of state and other equilibrium properties such as density, internal energy, enthalpy, entropy, specific heat capacity, sound speed, refractive index, surface or interfacial tension, etc. • Transport properties for the characterization of molecular transfer of mass, energy, and momentum, e.g. diffusion

		coefficients, Soret coefficient, thermal diffusion coefficient, thermal conductivity, thermal diffusivity, and viscosity • Use-oriented inquiry of thermophysical property data in scientific literature, table compilations, and databases • Correlation and prediction of thermophysical properties • Methods for experimental determination and in-process measurement of thermophysical properties, in particular by laser-optical techniques • Basics of the theoretical prediction of thermophysical properties by molecular modeling • Development of thermal and caloric equations of state
6	**Learning objectives and skills**	Die Studierenden • sind mit der Bedeutung von Stoffdaten in der Verfahrens- und Energietechnik in Form von Gleichgewichts- und Transporteigenschaften vertraut, • verwenden verschiedene Bezugsquellen für Stoffeigenschaften (Recherche in wissenschaftlicher Literatur, Tabellenwerken und Datenbanken; Korrelationen und Vorhersagemethoden; theoretische und experimentelle Bestimmung) eigenständig und wählen diese bedarfsgerecht und abhängig vom resultierenden Nutzen und Aufwand aus, • kennen die Herangehensweisen zur Korrelation und Vorhersage von Stoffeigenschaften sowie zur Aufstellung von thermischen und kalorischen Zustandsgleichungen und übertragen diese Herangehensweisen auf andere Stoffe, • sind mit experimentellen Methoden zur Stoffdatenbestimmung vertraut, insbesondere mit laseroptischen Messtechniken, • verstehen die Grundzüge der molekularen Modellierung zur theoretischen Bestimmung von Stoffdaten und • wählen Arbeitsmedien mit definierten Stoffeigenschaften für eine optimierte Gestaltung von Verfahren und Prozessen der Energie- und Verfahrenstechnik aus. *Education objectives and competences* The students • are aware of the importance of thermophysical properties in process and energy engineering in the form of equilibrium and transport properties, • use various sources for thermophysical properties (scientific literature, table compilations, databases, correlations, predictions, theoretical and experimental determination) independently and select the respective sources in a use-oriented way considering the resulting effort and benefit, • know the approaches for the correlation and prediction of thermophysical properties as well as for developing equations of state, and are able to transfer these approaches to other systems, • are familiar with experimental methods for the determination of thermophysical properties, in particular with laser-optical methods,

		• understand the basics of the use of molecular modeling for the theoretical determination of thermophysical properties, • select working materials with defined thermophysical properties for an optimized design of processes in energy and process engineering.
7	**Prerequisites**	Grundkenntnisse der Technischen Thermodynamik sowie der Wärme-, Stoff- und Impulsübertragung Basic knowledge on Engineering Thermodynamics as well as heat, mass, and momentum transfer
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• R. C. Reid, J. M. Prausnitz, B. E. Poling, The properties of gases and liquids, McGraw Hill Book Co., New York, 1987 • Recommended Reference Materials for the Realization of Physicochemical Properties, K. N. Marsh (ed.), Blackwell Scientific Publications, Oxford, 1987 • Measurement of the Transport Properties of Fluids, W. A. Wakeham, A. Nagashima, and J. V. Sengers (eds.), Blackwell Scientific Publications, Oxford, 1991 • R. Haberlandt, S. Fritzsche, G. Peinel, K. Heinzinger, Molekulardynamik: Grundlagen und Anwendungen, Vieweg, Braunschweig/Wiesbaden, 1995 • R. W. Kunz, Molecular Modelling für Anwender, Teubner, Stuttgart 1997 • M. J. Assael, J. P. M. Trusler, T. F. Tsooakis, Thermophysical Properties of Fluids, Imperial College Press, London, 1996 • Transport Properties of Fluids, J. Millat, J. H. Dymond, and C. A. Nieto de Castro (eds.), Cambridge University Press, Cambridge, 1996

		• J. M. Haile, Molecular Dynamics Simulation: Elementary Methods, John Wiley & Sons, Inc., Canada, 1997 • G. Grimvall, Thermophysical Properties of Materials, Elsevier, Amsterdam, 1999 • J. A. Wesselingh, R. Krishna, Mass Transfer in Multicomponent Mixtures, Delft University Press, Delft, The Netherlands, 2000 • Equations of State for Fluids and Fluid Mixtures, J. V. Sengers, R. F. Kayser, C. J. Peters, and H. J. White, Jr. (eds.), Elsevier, Amsterdam 2000 • Measurement of the Thermodynamic Properties of Single Phases, A. R. H. Goodwin, K. N. Marsh, and W. A. Wakeham (eds.), Elsevier, Amsterdam 2003 • Diffusion in Condensed Matter, P. Heitjans and J. Kärger (eds.), Springer, New York 2005 • R. B. Bird, W. E. Stewart, E. N. Lightfoot, Transport Phenomena, John Wiley & Sons, Inc., U.S.A., 2007 • C. L. Yaws, Thermophysical Properties of Chemicals and Hydrocarbons, William Andrew, Inc., Norwich, 2008 • Applied Thermodynamics of Fluids, A. R. H. Goodwin, J. V. Sengers, C. J. Peters (eds.), Elsevier, Amsterdam, 2010 • Experimental Thermodynamics Volume IX: Advances in Transport Properties of Fluids, M. J. Assael, A. R. H. Goodwin, V. Vesovic, and W. A. Wakeham (eds.), Royal Society of Chemistry, Cambridge, 2014

Optical Material Processing

1	**Module name** 42130	**Advanced Laser**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Advanced Laser (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly	

4	**Module coordinator**	Dr. Jürgen Grossmann Prof. Dr. Nicolas Joly
5	**Contents**	This module naturally follows the "Basics of Lasers module and aims at deepen the knowledge on a few specific aspects of lasers. In particular we will study the Z-cavity of one of the most popular laser system: the Titanium: sapphire laser. The purpose here is to show why simpler cavity is not possible. It requires understanding properly the concept of stability of laser cavity and introduces the problem of astigmatism. In a second stage we see how dispersion effects can hamper the properties of a mode-locked laser system and see how to circumvent this. We then study the different method used to characterize ultrashort laser pulse. This starts from basics concepts of autocorrelation but review more advanced techniques allowing to retrieve fully the amplitude and phase of a laser pulse. Towards the end of the lecture several topics are possible and it will be chosen together with the students. This can be for instance (i) the polarization and the Jones formalism (ii) the Maxwell-Bloch equations (iii) the origin of spontaneous emission. Finally in order to broaden the contents of the lecture the students are asked to prepare one half-an-hour presentation of the topics of their choice. The topics are discussed during the first two sessions of the lecture and must focus on a physical aspect of laser.
6	**Learning objectives and skills**	Students • Understand the problem of dispersion in a laser cavity and establish a strategy to balance this problem in order to achieve transform-limited ultrashort pulses • Estimate the duration of a laser pulse and adapt the technique to the level of precision required • Understand the design of laser cavities
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Material Processing Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• "Laser by A.E. Siegman, University Science book, 1986 • "Handbook of Lasers and Optics by F. Träger, Springer, 2007 • "Les lasers by D.Dangoisse, D. Hennequin and V. Zehnlé)Dhaoui, Dunod 1998 • "Principles of Lasers, 5th ed. by Orazio Svelto, Springer 2010 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

1	**Module name** 94930	**Engineering of Solid State Lasers** Engineering of solid state lasers	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Engineering of Solid State Lasers (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Martin Hohmann	

4	**Module coordinator**	Prof. Dr.-Ing. Michael Schmidt
5	**Contents**	The targeted audience is master level students who are interested in expanding their theoretical and practical knowledge in the field of solid state laser engineering. Introduction to physical phenomena used in development of modern solid state lasers Practical approaches used in design of solid state lasers Introduction to modeling and simulation of the lasing process Modeling of basic solid state laser performance using a commercial software package Practical familiarization with various optical, opto-mechnical, and opto-electrical components used in solid state laser
6	**Learning objectives and skills**	The students gain the following competences: Setting up basic modeling of a solid state laser using ASLD software Be able to apply modeling for evaluation of performance of a basic laser system Apply basic optimization of the laser system model Identification of an appropriate laser system for a given application Performing basic characterization of laser beam output parameters Enhanced understanding of the laser physics Familiarization with modern design approaches used in solid state laser engineering Improved understanding of linear and nonlinear effects relevant for linear and nonlinear laser beam propagation;
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 95360	**Lasersystemtechnik 1** Laser systems engineering 1	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Lasersystemtechnik 1 (2 SWS)	-
3	Lecturers	Prof. Dr. Peter Hoffmann	

4	**Module coordinator**	Prof. Dr. Peter Hoffmann
5	**Contents**	• Einführung: Weltmarkt für Lasersysteme, Strahlquellen und deren Anwendung in der Materialbearbeitung • Grundlagen zur Ausbreitung und Fokussierung von Laserstrahlung • CO2-Laseranlagen: Strahlerzeugung, Bauformen für Strahlquellen, Strahlführung und formung, Anlagenbeispiele, Anwendungen • Festkörper-Laseranlagen: Strahlerzeugung, Bauformen, Strahlführung über Lichtleitkabel, Strahlformung, Anlagenbeispiele, Anwendungen • Hochleistungdioden-Laseranlagen: Strahlerzeugung, Strahlführung und formung, Anlagenbeispiele, Anwendungen • Neuere Entwicklungen bei Strahlquellen und Laseranlage • Introduction: Global Market for Laser Systems, Beam Sources and their application in material processing • Fundamentals of Propagation and Focussing of laser radiation • CO2-Laser Systems: Beam Generation, design of beam sources, beam guidance and shaping, examples of systems, Applications • Solid-State-Laser Systems: Beam Generation, design, beam guidance via light conducting cable, beam shaping, examples of systems, Applications • High-Power-Diode-Laser Systems: Beam Generation, beam guidance and shaping, examples of systems, Applications • Novel developments in beam sources and Laser Systems
6	**Learning objectives and skills**	Die Studierenden können den Weltmarkt für Lasersysteme, Strahlquellen und deren Anwendung in der Materialbearbeitung korrekt beschreiben. Die Grundlagen zur Ausbreitung und Fokussierung von Laserstrahlung werden so weit beherrscht, dass die Lernenden im Rahmen der geometrischen Optik überschlagsweise die Auslegung von Anlagen berechnen können. Bauformen für CO2-Strahlquellen Strahlführung und formung können die Lernenden skizzieren. Sie erläutern sicher die Anwendungen für Anlagen mit Festkörperlasern, deren Bauformen, die Strahlerzeugung, -führung über Lichtleitkabel und formung. Das Prinzip der Strahlerzeugung in Hochleistungsdiodenlasern können lernende darstellen, ebenso wie dafür geeignete Systeme zur Strahlführung, -formung und Anwendungen mit dazugehörigen Anlagenbeispielen. Die Lernenden können über neueste Entwicklungen bei Strahlquellen und Laseranlagen berichten.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 97283	**Lasersystemtechnik II**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Lasersystemtechnik 2 (2 SWS)	-
3	Lecturers	Sven Ackermann Prof. Dr. Peter Hoffmann	

4	**Module coordinator**	Prof. Dr. Peter Hoffmann
5	**Contents**	1.Programmierung von Laseranlagen, Führungsverhalten 2.Erzeugung von Verfahrbefehlen und deren Umsetzung in eine Vorschubbewegung 3.Kommunikationstechniken für die Steuerung und Automatisierung von Laseranlagen 4.Neuere Entwicklungen für Laserroboter" 5.Spanntechnik für das Laserstrahlschneiden 6.Spanntechnik für das Laserstrahlfügen 7.Sicherheit von Laseranlagen Exkursion zur ERLAS GmbH
6	**Learning objectives and skills**	Die Studierenden können die Programmierung von Laseranlagen und Führungsverhalten zusammenfassend darstellen. Die Erzeugung von Verfahrbefehlen und deren Umsetzung in eine Vorschubbewegung kann von den Lernenden erklärt und berechnet werden. Die Lernenden sind in der Lage, Kommunikationstechniken für die Steuerung und Automatisierung von Laseranlagen zu unterscheiden und einzuordnen. Sie können neuere Entwicklungen für Laserroboter beschreiben und nach ihrer Eignung für Anwendungsfälle einteilen. Spanntechnik für das Laserstrahlschneiden und Laserstrahlfügen können die Lernenden skizzieren. Maßnahmen zur Gewährleistung der Arbeitssicherheit von Laseranlagen können die Lernenden erläutern.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (20 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 97150	**Lasertechnik / Laser Technology** Laser technology	**5 ECTS**
2	Courses / lectures	Vorlesung: Laser Technology (4 SWS)	5 ECTS
3	Lecturers	Clemens Roider Dr. Kristian Cvecek	

4	**Module coordinator**	Dr. Kristian Cvecek
5	**Contents**	• 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
6	**Learning objectives and skills**	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 spac e 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.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222

10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 763337	**Laser Tissue Interaction** Laser tissue interaction	**5 ECTS**
2	Courses / lectures	Vorlesung: Laser Tissue Interaction (2 SWS) Übung: Laser Tissue Interaction Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Florian Klämpfl Dr.-Ing. Martin Hohmann	

4	**Module coordinator**	Dr.-Ing. Florian Klämpfl
5	**Contents**	
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	no Bibliography information available!

1	**Module name** 42140	**Optical Lithography: Technology, Physical Effects and Modeling**	**5 ECTS**
2	Courses / lectures	Vorlesung: Halbleitertechnologie IV - Optical Lithography: Technology, Physical Effects, and Modelling (2 SWS) Übung: Übung zu Halbleitertechnologie IV - Optical Lithography (2 SWS)	- -
3	Lecturers	PD Dr. Andreas Erdmann	

4	**Module coordinator**	PD Dr. Andreas Erdmann
5	**Contents**	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 aper-ture 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.
6	**Learning objectives and skills**	The goals of this lecture are 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
7	**Prerequisites**	• abgeschlossens Grundstudium / B.Sc. • Grundlagen der Optik und Elektotechnik
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222

		Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• 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.

1	**Module name** 46100	**Scannen und Drucken in 3D** Scanning and printing in 3D	**5 ECTS**
2	Courses / lectures	Übung: Übung Scannen und Drucken in 3D (1 SWS) Vorlesung mit Übung: Scannen und Drucken in 3D (3 SWS)	- -
3	Lecturers	Michael Blank Dr. Patric Müller	

4	**Module coordinator**	Dr. Patric Müller
5	**Contents**	- Stereo-Imaging - Scannen dreidimensionaler Objekte - Computer-Tomographie und verwandte Techniken - 2D Darstellung dreidimensionaler Datensätze - 3D Bildverarbeitung - 3D Druck-Verfahren - 3D Projektion und Darstellung - Darstellung wissenschaftlicher Daten mittels "Virtueller Realität (VR)
6	**Learning objectives and skills**	Die Studierenden: - beherrschen die physikalischen und technischen Grundlagen zur Aufnahme dreidimensionaler Bilder mittels Stereokameraverfahren, 3D Scannern sowie Computer-Tomographie. - können dreidimensionale Datensätze erfassen, numerisch bearbeiten und wissenschaftlich darstellen. - gehen mit gängigen 3D Druckverfahren sicher um und implementieren diese als wissenschaftliches Werkzeug. - setzen mathematisch/physikalische Konzepte dreidimensionaler Darstellung mittels 3D Projektions- und Display-Verfahren sowie VR-Techniken um.
7	**Prerequisites**	Matlab-Grundlagen dringend empfohlen!
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written or oral (120 minutes)
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	- Gregor Honsel, Rapid Manufacturing

		- Lee Goldmann, Principles of CT and CT Technology - Okoshi, Three-Dimensional Imaging Techniques

Optics in Medicine

1	**Module name** 67112	**Advanced microscopic techniques** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Hauptseminar: Advanced Microscopic Techniques (0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Vahid Sandoghdar Kanwarpal Singh	

4	**Module coordinator**	Prof. Dr. Vahid Sandoghdar
5	**Contents**	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 non linear 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.
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 47664	**Fundamentals in Anatomy and Physiology for Engineers** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Fundamentals in Anatomy and Physiology for Engineers (4 SWS)	-
3	Lecturers	Benedikt Kleinsasser Prof.Dr.med. Friedrich Paulsen	

4	**Module coordinator**	apl.Prof.Dr. Michael Eichhorn
5	**Contents**	• Biological Systems • Trunk System • Nervous System • Respiration • Circulation • Heart • Digestion • Neuroscience • Functional cardiology • Advanced endoscopy • Advanced neuroimaging
6	**Learning objectives and skills**	Students are able to • describe relevant structures of the human anatomy and basic physiological processes • understand features of biological systems when applying optical technologies to them • describe exemplarily applications of optical technologies in medicine
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Gerard J. Tortora, Bryan Derrickson: Principles of Anatomy and Physiology:

1	**Module name** 763337	**Laser Tissue Interaction** Laser tissue interaction	**5 ECTS**
2	Courses / lectures	Vorlesung: Laser Tissue Interaction (2 SWS) Übung: Laser Tissue Interaction Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Florian Klämpfl Dr.-Ing. Martin Hohmann	

4	**Module coordinator**	Dr.-Ing. Florian Klämpfl
5	**Contents**	
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Material Processing Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	no Bibliography information available!

1	**Module name** 67124	**Light as a versatile tool in biology and biophysics** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Light as a versatile tool in biology and biophysics (2 SWS)	5 ECTS
3	Lecturers		

4	**Module coordinator**	Prof. Dr. Birgit Stiller
5	**Contents**	Light can be used to examine biological systems such as human cells, bacteria, or viruses in various ways. In this seminar, we will explore this fascinating field, such as realizations in optogenetics, model systems, and correlative approaches (Katja Zieske) as well as fluorescence, super-resolution microscopy, image analysis, and deep learning (Leonhard Möckl). Each participant will prepare a talk on one of the topics listed below (or related ones), give a talk, and discuss the topic with the other students. Key topics covered: 1. Principles of fluorescence 2. Labeling approaches for microscopy of biological systems 3. Localization-based super-resolution microscopy 4. Single-molecule and single-particle tracking 5. STED 6. Expansion microscopy 7. Image analysis 8. Deep learning-based approaches 9. AFM 10. Fluorescence correlation spectroscopy 11. Confocal microscopy + applications 12. Microfluidics 13. Lipid membranes 14. Optogenetic switches 15. Biological patterns
6	**Learning objectives and skills**	Understand the specific advantages and challenges of light-based approaches in biology; learn to read and contextualize publications; present and discuss scientific findings.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h

15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	provided for each individual topic

1	**Module name** 122337	**Magnetic Resonance Imaging** Magnetic resonance imaging	**5 ECTS**
2	Courses / lectures	Übung: Magnetic Resonance Imaging 1 - Übung (2 SWS) Vorlesung: Magnetic Resonance Imaging 1 (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Armin Michael Nagel Prof. Dr. Frederik Bernd Laun Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	Prof. Dr. Frederik Bernd Laun Prof. Dr.-Ing. Andreas Maier
5	**Contents**	In this module,the physical and technical basics of MRI are taught in detail. The principles of data acquisition are explained and various examples are shown. Imperfections in the data acquisition lead to image artifacts that cannot be avoided in all cases. Strategies for detecting and avoiding image artifacts are explained. One of the great strengths of MRI in medical diagnostics is the ability to acquire images with different contrasts. The origin of the frequently used T1 and T2 weighted image contrasts is discussed in detail. Various MRI sequence techniques are also discussed."
6	**Learning objectives and skills**	The participants • understand the principles, properties and limits of basic MRI techniques • develop the ability to choose an appropriate basic MRI sequence and to set up the corresponding sequence parameters for a range of basic applications • are able to explain MRI techniques, algorithms and concepts of the lecture to other engineers.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	no Bibliography information available!

1	**Module name** 568977	**Magnetic Resonance Imaging 2 + Übung** Magnetic resonance imaging 2 + exercise	**5 ECTS**
2	Courses / lectures	Vorlesung: Magnetic Resonance Imaging 2 (2 SWS) Übung: Magnetic Resonance Imaging 2 - Übung (0 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Armin Michael Nagel Prof. Dr. Frederik Bernd Laun Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	Prof. Dr. Frederik Bernd Laun Prof. Dr.-Ing. Andreas Maier
5	**Contents**	In der Vorlesung werden fortgeschrittene Techniken der Magnetresonanztomographie (MRT) erklärt. Vorausgesetzt werden Kenntnisse über Grundlagen des Gebietes, wie sie z.B. in der Vorlesung Magnetic resonance imaging 1" behandelt werden (Blochgleichungen, T1- und T2-Wichtung, Schichtselektion, k-Raum-Kodierung). U.a. folgende Themen werden behandelt: Echoplanare Bildgebung; Bildgebung des Flusses, der Perfusion, der Diffusion, der magnetischen Suszeptibilität; funktionelle MRT; Ultrahochfeld-MRT; CEST-Bildgebung; MRT-Technik; Beschleunigungsverfahren, z.B. parallele Bildgebung; Angiographie; Bewegungskompensation. The lecture covers advanced topics in magnetic resonance imaging (MRI). Knowledge about the basic principles of MRI are required as they are covered in the lecture Magnetic Resonance Imaging 1" (Bloch equations, T1 and T2 weighting, slice selection, k-space encoding). I.a. the following topics will be treated: echo planar imaging; imaging of flow, perfusion, diffusion, magnetic susceptibility; functional MRI; ultrahigh field MRI; chemical exchange saturation transfer imaging; MRI technique; acceleration methods, e.g. parallel imaging; angiography; motion compensation.
6	**Learning objectives and skills**	The participants • understand the principles, properties and limits of advanced MRI techniques • develop the ability to adapt basic principles of MRI to advanced MRI techniques • are able to explain MRI techniques, algorithms and concepts of the lecture to other engineers.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	no Bibliography information available!

1	**Module name** 44151	**Medical Image Processing for Diagnostic Applications**	**5 ECTS**
2	Courses / lectures	Vorlesung: Medical Image Processing for Diagnostic Applications (VHB-Kurs) (4 SWS)	5 ECTS
3	Lecturers	Manuela Meier Arpitha Ravi Luis Rivera Monroy	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	English version: 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. Deutsche Version: Die Inhalte des Moduls umfassen Grundlagen der medizinischen Bildverarbeitung und Aufnahmeprinzipien. Darüber hinaus werden Details der Vorverarbeitung für Bildverstärker, Flachpaneldetektoren und MR erklärt. Die Grundlagen der Rekonstruktion von Parallelstrahl bis hin zur Kegelstrahl-Tomographie werden ebenfalls behandelt. Im letzten Kapitel wird starre Registrierung für Bildfusion erläutert.
6	**Learning objectives and skills**	English Version: 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. Deutsche Version: Die Teilnehmenden • verstehen die Herausforderungen in der interdisziplinären Arbeit zwischen Ingenieuren und Ärzten. • entwickeln Verständnis für Algorithmen und Mathematik der diagnostischen medizinischen Bildverarbeitung. • erfahren, dass kreative Adaption von bekannten Algorithmen auf neue Probleme der Schlüssel für ihre berufliche Zukunft ist. • entwickeln die Fähigkeit Algorithmen auf verschiedene Probleme anzupassen. • sind in der Lage, Algorithmen und Konzepte des Moduls anderen Studierenden der Technischen Fakultät zu erklären.
7	**Prerequisites**	Ingenieurmathematik

8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 44141	**Medical Image Processing for Interventional Applications**	**5 ECTS**
2	Courses / lectures	Vorlesung: Medical Image Processing for Interventional Applications (VHB-Kurs) (4 SWS)	5 ECTS
3	Lecturers	Manuela Meier Arpitha Ravi Luis Rivera Monroy	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	English Version: 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. Deutsche Version: Das Modul ist auf die jüngsten Entwicklungen in der Verarbeitung von medizinischen Bildern ausgerichtet. Alle Algorithmen werden durch praktische Probleme motiviert. Die mathematischen Werkzeuge, die für die Bildverarbeitungsaufgaben benötigt werden, werden eingeführt. Das Modul beginnt mit einem Überblick über Vorverarbeitungsalgorithmen, wie zum Beispiel Streustrahlkorrektur für Röntgenbilder, Kantenerkennung, Superresolution und kantenerhaltende Rauschunterdrückung. Das zweite Kapitel beschreibt die automatische Bildanalyse mit Merkmalsdeskriptoren, Punkterkennung und Segmentierung mit Bottom-up-Algorithmen wie dem Random-Walker oder Top-Down-Ansätzen wie aktiven Formmodellen. Darüber hinaus deckt die Vorlesung auch geometrische Kalibrierungsalgorithmen zur Einzelansicht-Kalibrierung, Epipolargeometrie und Faktorisierung ab. Der letzte Teil des Moduls deckt nicht-starre Registrierung auf der Grundlage von Variationsmethoden und bewegungskompensierter Bildrekonstruktion ab.
6	**Learning objectives and skills**	English Version: 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. Deutsche Version: Die Teilnehmenden • fassen die Inhalte der Vorlesung zusammen. • wenden Vorverarbeitungsalgorithmen wie Streustrahlkorrektur und kantenerhaltende Filterung an. • extrahieren automatisch Informationen aus Bildern, indem sie Bildanalyseverfahren wie Punktdetektoren und Segmentierungsalgorithmen verwenden. • kalibrieren Projektionsgeometrien für Einzelbilder und Bildsequenzen mit den beschriebenen Methoden. • entwickeln nicht-starre Registrierungsmethoden mit Hilfe von Variationsrechnung und unterschiedlichen Regularisierern. • wenden Algorithmen auf neue Modalitäten durch entsprechende Änderungen im Algorithmus an.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 45730	**Optical Technologies in Life Science** Optical technologies in life science	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Optical Technologies in Life Science (4 SWS)	5 ECTS
3	Lecturers	Lucas Kreiß Prof.Dr.Dr. Oliver Friedrich PD Dr.habil. Sebastian Schürmann Prof. Dr. Maximilian Waldner	

4	**Module coordinator**	PD Dr.habil. Sebastian Schürmann
5	**Contents**	Inhalte • Anwendungen optischer Messmethoden im Bereich der Zellbiologie und Medizin • Mikroskopie: Grundlegende Konzepte und Kontrastverfahren, Auflösungsvermögen und Grenzen, Aufbau und Komponenten von Lichtmikroskopen, Fluoreszenz-Mikroskopie • Anwendungen von Fluoreszenz-Mikroskopie im Life Science Bereich, Verfahren zur Markierung biologischer Strukturen und Vorgänge in Zellen • Epifluoreszenz-, Konfokal-, Multiphotonen-Mikroskopie, Konzepte und Anwendungsbeispiele • Optische Endoskopie und Endomikroskopie in Forschung und Klinik • Super-Resolution Mikroskopie, Konzepte und Anwendungsbeispiele für optische Bildgebung jenseits der beugungsbedingten Auflösungsgrenze 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
6	**Learning objectives and skills**	Lernziele und Kompetenzen Die Studierenden • verstehen die grundlegenden Konzepte und technische Umsetzung optischer Technologien im Bereich Life Sciences und kennen typische Anwendungsbeispiele

		• können verschiedene technische Ansätze im Hinblick auf wissenschaftlich Fragestellungen vergleichen und bewerten • können Vor- und Nachteile verschiedener Technologien, sowie konzeptionelle und praktische Limitationen einschätzen und bei der Analyse wissenschaftlicher Ansätze und Ergebnisse berücksichtigen • können selbstständig vertiefende Informationen zu technischen Lösungen, Materialien und Methoden im Bereich der Mikroskopie und Spektroskopie sammeln, strukturieren, und für die zielgerichtete Planung wissenschaftlicher Experimente auswählen • können wissenschaftliche Fragestellungen und technische Ansätze in Kleingruppen kritisch diskutieren und gemeinschaftlich Ansätze zur Beantwortung von Forschungsfragen mit Hilfe optischer Technologien entwickeln Learning objectives and competences: 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.
7	**Prerequisites**	• Grundkenntnisse im Bereich Optik und Zellbiologie • Basic knowledge in the fields of optics and cell biology is required
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester

16	**Teaching and examination language**	english
17	**Bibliography**	• 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.

1	**Module name** 47650	**Medizintechnische Anwendungen der Photonik** Photonics for medical applications	**5 ECTS**
2	Courses / lectures	Vorlesung: Medizintechnische Anwendungen der Photonik (2 SWS) Übung: Medizintechnische Anwendungen der Photonik Übung (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Bernhard Schmauß Dr.-Ing. Christian Carlowitz	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Das Modul behandelt spezialisiert medizintechnische Anwendungen der Photonik. Zunächst wird die Lichtausbreitung in biologischem Gewebe beschrieben und diskutiert. Ein weiterer Abschnitt behandelt die Wechselwirkung zwischen Licht und Gewebe, wobei die einzelnen Wechselwirkungsmechanismen auch an Beispielen der medizintechnischen Praxis vertieft werden. Hier sind stellvertretend zu nennen: Photodynamische Therapie, Photokoagulation, Laser-in-situ-Keratomileusis (LASIK). Ein weiterer Themenschwerpunkt ist die Diskussion entsprechender diagnostische Verfahren. Hier wird beispielsweise aus spektroskopische Verfahren und auf Diagnoseverfahren die auf Fluoreszenz basieren detailliert eingegangen. Entsprechende Konzepte von Diagnosegeräten wie Endoskope, konfokale Mikroskope, Optische Kohärenztomographie (OCT), faserbasierte Sensoren und Biochipsensoren werden in einem weiteren Abschnitt vertieft. Ein aktueller Forschungsbezug wird im letzten Kapitel, das photonische Systeme in der Ophthalmologie behandelt, hergestellt. Die Lehrveranstaltung des Moduls teilt sich auf in einen Vorlesungsteil sowie einen Übungsteil, in dem die Studierenden durch eigene Beiträge (angeleitete Literaturrecherche, Kurzvorträge und Praxisprojekte) die Inhalte der Vorlesung vertiefen.
6	**Learning objectives and skills**	Die Studierenden • besitzen spezialisiertes und vertieftes Wissen der medizintechnische Anwendungen der Photonik, insbesondere der im Inhalt genannten Themengebiete. • können technische und wissenschaftliche Anwendungen der Photonik diskutieren, beurteilen und vergleichen. • sind in der Lage, ihre theoretischen Kenntnisse zur Photonik und Lasertechnik im Bereich der Medizintechnik vergleichend einzusetzen und so neue Verfahren und Konzepte zu entwickeln und auszuarbeiten. • können eigenständige Ideen und Konzepte zur Lösung wissenschaftlicher und technischer Probleme der Medizintechnik mit photonischen Systemen entwickeln.
7	**Prerequisites**	*Voraussetzungen:*

		• Für Studenten im Master-Studium. • "Photonik 1", oder anderweitig erworbene fundierte Kenntnisse im Bereich Optik, Photonik und Lasertechnik.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	• [1]Prahl, S.A.:Light Transport in Tissue, Dissertation, December 1988 • [2]Niemz, M.:Laser-Tissue Interaction, Springer, 2007 • [3]Cox, B.T.:Introduction in Laser Tissue Interaction, 2007 • [4]Welch, A. (Hrsg):Optical-Thermal Response of Laser-Irradiated Tissue, Springer, 2011 • [5]Prasad, P.N.:Introduction to Biophotonics, Wiley, 2003 • [6]Tuchin, V.:Handbook of Photonics for Biomedical Science, CRC Press,Wiley, 2010 • [7]Dithmar, S. et.al.Fluorezenzangiographie in der Augenheilkunde, Springer, 2008 • [8]Fercher, A.:Optical coherence tomography - principles and applications, Rep. Prog. Phys. 66 , pp.: 239, 2003 • [9]Schröder, G.:Technische Optik, Vogel Buchverlag, 9. Auflage, 2002 • [10]Lang, G.:Augenheilkunde, Thieme Verlag, 3. Auflage, 2004 • [11]Grehn, F.:Augenheilkunde, Springer Verlag, 3. Auflage, 2007

1	**Module name** 47607	**Seminar Intraoperative Imaging and Machine Learning** no english module name available for this module	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof.Dr.Ing. Katharina Breininger
5	**Contents**	For many applications, techniques like deep learning allow for considerably faster algorithm development and allow to automate tasks that were performed manually in the past. In medical imaging, a large variety of time-consuming tasks that interfere with clinical workflows has the potential for automation. However, at the same time new challenges arise like data privacy regulations and ethics concerns. In this seminar, we want to develop an application that allows for the automation of an X-ray based intraoperative planning or measurement procedure from a holistic perspective. To this end, we will invite a surgeon to explain the medical background and visit the operating room to understand the surgeons needs while performing the task. Having understood the underlying medical problem, we will look into topics of data privacy, code of ethics, prototype development, and UI design for surgeons. Furthermore, we will touch regulatory requirements necessary for releasing software to clinics. At the end of the seminar, the students will have developed and documented a prototypical application for the indented intraoperative use case.
6	**Learning objectives and skills**	Students will be able to • visit an operation room, following the rules of such an environment • perform their own literature research on a given subject • independently research this subject according to data privacy and ethical standard • present and introduce the subject to their student peers • give a scientific talk in English according to international conference standards • describe their results in a scientific report
7	**Prerequisites**	Students are required to have initial experience with deep learning and machine learning, e.g., from the module "Deep Learning". This seminar is recommended for Master's students.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement

11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

Optics in Communication and IT

1	**Module name** 67143	**Advanced nonlinear optics** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced nonlinear optics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi	

4	**Module coordinator**	Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi Prof. Dr. Nicolas Joly
5	**Contents**	*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)
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h

15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 621649	**Advanced Optical Communication Systems** Advanced optical communication systems	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Optical Communication Systems (2 SWS) Übung: Advanced Optical Communication Systems Exercises (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Bernhard Schmauß Lisa-Sophie Härteis	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	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
6	**Learning objectives and skills**	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.
7	**Prerequisites**	**Prerequisites:** • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Portfolio

11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	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.

1	**Module name** 67111	**Arduino hard- and software for lab applications and beyond** no english module name available for this module	**2,5 ECTS**
2	Courses / lectures	Praktikum: Arduino hard- and software for lab applications and beyond (5 SWS)	2,5 ECTS
3	Lecturers	Dr. Max Gmelch	

4	**Module coordinator**	Dr. Max Gmelch
5	**Contents**	Please check StudOn for **registration and further information**: Link to StudOn-Entry Nowadays, **microcontrollers are the centerpieces of electronics** in almost any device, including washing machines, vending machines, several parts of any car and, increasingly, in smart home applications. With processor, memory and peripherals in one chip, they represent a **full-fledged computer in miniature**, and some of them can be bought for just a few cents. This is why these controllers are very relevant for scientists as well. Specially in research laboratories, **individual and quick solutions** for controlling mechanics and devices for data logging are highly desired. A very suitable introduction to working with microcontrollers is the **Arduino platform**. With standardized hardware boards and its own development environment based on the programming language C, the main focus of Arduino is on the **rapid realization of new and individual projects**. Numerous code libraries and compatible hardware extensions such as WIFI boards, SD card slots, various sensors, smartphone interaction and much more enable **complex projects even for beginners**. The scope of the **two-week course** “Arduino hard- and software for lab applications and beyond” reaches from the understanding of basic hardware components and electronics to the implementation of a multitude of libraries and modules. In addition to theoretical lectures, each group of two to three students will **work on hard- and software every day**. In the **last few days** of the course, the students apply their knowledge in an **own project of their choice**. Thereby, first ideas to lab automation can be implemented.
6	**Learning objectives and skills**	Sound qualification in designing and realizing complex hard- and software projects using microcontrollers based on Arduino, including: • Basics of electronics and microcontrollers • Communication of microcontrollers • Analog and digital signals • Finite-state machine • Sensors, modules, shields • Software libraries • Displays • Smartphone connection
7	**Prerequisites**	Most important: Enthusiasm and curiosity about the topic

		Advantageous, but not mandatory: First experience in programming
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written
11	**Grading procedure**	Written (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	english
17	**Bibliography**	Programming Arduino: Getting Started with Sketches *by Simon Monk*, ISBN 978-1259641633

1	**Module name** 267499	**Linear and non-linear fibre optics**	**5 ECTS**
2	Courses / lectures	Übung: Linear and non-linear fibre optics: Exercise (2 SWS) Vorlesung: Linear and non-linear fibre optics (2 SWS)	- 5 ECTS
3	Lecturers	Lisa-Sophie Härteis Andreas Rittler Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.
6	**Learning objectives and skills**	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links
7	**Prerequisites**	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222

10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	**Module name** 48313	**Modern Optics 3: Quantum Optics** Modern optics 3: Quantum optics	**5 ECTS**
2	Courses / lectures	Vorlesung: Modern Optics 3: Quantum Optics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Maria Chekhova	

4	**Module coordinator**	Prof. Dr. Maria Chekhova
5	**Contents**	**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
6	**Learning objectives and skills**	**Learning goals and competences:** Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral PL: oral examination 30 Min.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	-

1	**Module name** 582360	**Modern Optics 2: Nonlinear Optics** Nonlinear optics	**5 ECTS**
2	Courses / lectures	Vorlesung: Modern Optics 2: Nonlinear Optics (2 SWS)	-
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Maria Chekhova	

4	**Module coordinator**	Prof. Dr. Nicolas Joly
5	**Contents**	*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.
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	*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)

1	**Module name** 849203	**Optische Kommunikationsnetze** Optical communication networks	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Optische Kommunikationsnetze (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Herbert Haunstein	

4	**Module coordinator**	Prof. Dr. Herbert Haunstein
5	**Contents**	Global communication between billions of subscribers utilizing a multitude of devices is accomplished over a trans-continental fiber-optic transport network. End users worldwide access this network over copper cable (xDSL, HFC), by wireless technologies like WLAN, GSM, UMTS, LTE and also via GPON, EPON and WDM-PON (PON: Passive Optical Network). After a short distance ("the last mile") data streams from many users are aggregated (e.g. by IP routers) into higher data rate transport streams, which are then carried over cost-efficient and highly reliable optical connections. Rapid increase of data traffic has quickly evolved from Gigabit Ethernet (1GbE) to 10GbE and 100GbE data rates. To operate optical networks on a global scale, standards like OTN (Optical Transport Network) have been developed to provide high capacity links by use of many wavelengths together with operations and maintenance (OAM) functions. Automated protection and restauration schemes provide a high level of availabilty and can guarantee carrier-grade Quality of Service (QoS). Future data rate increase will be driven by video streaming as well as the introduction of 5G wireless technology and the Internet of Things (IoT). The course shall provide a fundamental understanding of modern fiber optic networks from fixed and mobile access through metropolitan area to core networks. 1) Introduction – Evolution of optical networks 2) Network layers - Internet Protocol – TCP/IP 3) Label switching – MPLS – MPLS-TP 4) Quality of Service - traffic classification – resource allocation 5) Ethernet - switching and physical transport 6) Optical Transport Network - OTN 7) Optical fiber properties – optical amplification 8) Optical transmitter – laser – modulator 9) Optical receiver – photo detection – Clock&Data recovery – Bit Error Ratio calculation 10) Modulation formats – transmission - margin allocation 11) Coherent detection – optical signal processing 12) Optical networks – optical switching 13) Network control & automation
6	**Learning objectives and skills**	Students ... • explain the functional building blocks of optical networks

		• can eloborate on the different tasks provided by the logical/ control plane (routing), the physical layer and transmission/ data plane of optical networks • refer which standardisation organisation contributes to the different function of optical networks • explain the purpose of different protocols that interact along an end-to-end communication channel • describe technologies for E/O and O/E conversion and optical switches • express the design challenges of future optical systems for fixed and mobile access, data center interconnects, • metro-regional, core, ultra-long-haul and submarine networks
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	
17	**Bibliography**	1) R. Ramaswami and K.N. Sivarajan: “Optical Networks”, Morgan Kaufman Publishers, 1998 2) U. Black: “Optical Networks - Third generation transport systems”, Prentice Hall, 2002 3) P. Tomsu and Chr. Schmutzer: “Next generation optical networks”, Prentice Hall, 2002 4) M. Bossert, M. Breitbach: “Digitale Netze”, Teubner Verlag, 1997 5) I. Kaminow and T. Li (eds.): “Optical fiber telecommunications IVA+B”, Academic Press, 2002 6) D.E. Comer, „Computernetworks and Internets, Pearson“, 2009 7) G.P. Agrawal, “Fiber optic communication systems”, Wiley, 1992, (new 1997) 8) G.P. Agrawal, “Nonlinear fiber optics”, Academic Press, 1995 9) K. Petermann: “Laser Diode Modulation and Noise”, Kluver, 1991 10) L. Kazovsky et al., „Optical Fiber Communication Systems“, Artech House, 1996

		11) K.-P. Ho, „Phase-Modulated Optical Communication Systems“, Springer 2005 12) H. Haunstein, Presentation material (slides) of the lectures (in English)

1	**Module name** 67188	**Quantum Communication** Quantum communication	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Communication (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Christoph Marquardt Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr. Christoph Marquardt
5	**Contents**	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
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Will be provided individually for each talk.

1	**Module name** 67145	**Waveguides, optical fibres and photonic crystal fibres**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Waveguides, optical fibres and photonic crystal fibres (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

Optical Materials and Systems

1	**Module name** 42155	**Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (4 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics)(Laser exercise lab)(EV-AL) (1 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (Excercise class) (2 SWS)	10 ECTS - -
3	Lecturers	Prof. Dr. Joachim Zanthier Prof. Dr. Stephan Götzinger	

4	**Module coordinator**	Prof. Dr. Joachim Zanthier
5	**Contents**	*Contents* 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
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written (120 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 42130	**Advanced Laser**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Advanced Laser (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly	

4	**Module coordinator**	Dr. Jürgen Grossmann Prof. Dr. Nicolas Joly
5	**Contents**	This module naturally follows the "Basics of Lasers module and aims at deepen the knowledge on a few specific aspects of lasers. In particular we will study the Z-cavity of one of the most popular laser system: the Titanium: sapphire laser. The purpose here is to show why simpler cavity is not possible. It requires understanding properly the concept of stability of laser cavity and introduces the problem of astigmatism. In a second stage we see how dispersion effects can hamper the properties of a mode-locked laser system and see how to circumvent this. We then study the different method used to characterize ultrashort laser pulse. This starts from basics concepts of autocorrelation but review more advanced techniques allowing to retrieve fully the amplitude and phase of a laser pulse. Towards the end of the lecture several topics are possible and it will be chosen together with the students. This can be for instance (i) the polarization and the Jones formalism (ii) the Maxwell-Bloch equations (iii) the origin of spontaneous emission. Finally in order to broaden the contents of the lecture the students are asked to prepare one half-an-hour presentation of the topics of their choice. The topics are discussed during the first two sessions of the lecture and must focus on a physical aspect of laser.
6	**Learning objectives and skills**	Students • Understand the problem of dispersion in a laser cavity and establish a strategy to balance this problem in order to achieve transform-limited ultrashort pulses • Estimate the duration of a laser pulse and adapt the technique to the level of precision required • Understand the design of laser cavities
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Material Processing Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• "Laser by A.E. Siegman, University Science book, 1986 • "Handbook of Lasers and Optics by F. Träger, Springer, 2007 • "Les lasers by D.Dangoisse, D. Hennequin and V. Zehnlé)Dhaoui, Dunod 1998 • "Principles of Lasers, 5th ed. by Orazio Svelto, Springer 2010 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

1	**Module name** 46257	**Advanced Semiconductor Technologies** **Photovoltaic Systems I - Fundamentals** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Seminar and Conference Participation on Solar Energy (2 SWS) Vorlesung mit Übung: Advanced Semiconductor Technologies - Photovoltaic Systems for Power Generation - Design Implementation and Characterization (2 SWS) Praktikum: Lab Work Characterization and Advanced Defect Imaging of PV Modules and Systems (3 SWS)	2 ECTS 3 ECTS 2 ECTS
3	Lecturers	Ning Li Prof. Dr. Christoph Brabec Dr. Jens Hauch Dr. Andres Osvet	

4	**Module coordinator**	Prof. Dr. Christoph Brabec Prof. Dr. Wolfgang Heiß
5	**Contents**	Lecture / Exercise / Lab work The lecture will introduce into the fundamentals of photovoltaic energy conversion. The conversion of light into electricity is one of the most efficient power technologies by today and is expected to transform our energy system towards a renewable scenario. The limits of photovoltaic energy conversion, the materials and architectures of major PV technologies and advanced characterization methods for modules as well as solar fields will be introduced theoretically and experimentally during the lecture, a seminar and the lab works.
6	**Learning objectives and skills**	• The students will learn the concept of black body radiation and the radiation laws and the limits of light energy conversion. The fundamental semiconductor junctions (p-n, M-i-M, Shottky and Hetero Junction are repeated. The one diode and two diodes replacement circuits are explained . Electrical, optical, recombination and extraction loss mechanisms are discussed separately and demonstrated at the hand of numerical drift-diffusion equation solvers. The most important solar cell concepts (Si, CIGS, CdTe, GaAs, Perovksites, Organics) are introduced, and the strengths and weaknesses of each technology are analysed. • Characterization of Photovoltaic Modules will trained by flashed measurements in the lab. Defect imaging methods like DLIT, EL or PL imaging will be trained at the hand of module installations in Erlangen.
7	**Prerequisites**	Bachelor in Material Science, Nanotechnology, Energy Technology, Electronic Engineering, Computer Science, Physics, Chemistry, Chemical Engineering , Nanotechnologie, Energietechnik, Elektrotechnik, Physik, Chemie or comparable
8	**Integration in curriculum**	semester: 1

9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable Advanced Semiconductor Technologies – Photovoltaic Systems I - Fundamentals (Prüfungsnummer: 62571) Prüfungsleistung, mündliche Prüfung, Dauer (in Minuten): 15, benotet, 5 ECTS Anteil an der Berechnung der Modulnote: 100.0 % weitere Erläuterungen: mögliche weitere Prüfungsformen sind Klausur (45 Min.) oder Hausarbeit benotet (ca. 20 Seiten) • Lab Work: 2 practicals with final reports of approximately 11-15 pages OR • participation and a talk at the Solar Energy Seminar Prüfungssprache: Deutsch oder Englisch
11	**Grading procedure**	Variable (100%) Advanced Semiconductor Technologies – Photovoltaic Systems I - Fundamentals (Prüfungsnummer: 62571) Anteil an der Berechnung der Modulnote: 100.0 %
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 40 h Independent study: 110 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 46228	**Glas I** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Neuer Master: WS-Vibrational spectroscopies, from theory to practice (2 SWS) Vorlesung mit Übung: Neuer Master: WS-Optical properties of glasses (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Dominique Ligny	

4	**Module coordinator**	Prof. Dr. Dominique Ligny
5	**Contents**	|Optical properties of glasses| • Fundamental concepts: The electromagnetic spectrum and units, Absorption, Luminescence, Scattering • Optical transparency of solids: Optical magnitudes and the dielectric constant, The Lorentz Oscillator, Metals, Semiconductors and insulators, Excitons, Reflection and polarization • Optical glasses: Optical aberration and solutions, Dispersion properties and composition • Colors in glasses: The eye, Optically Active Centers, Transition metals in glasses, Metallic and Chalcogenide nanoparticles • Chromism: Thermochromism, Photochromism, Gasochromism, Electrochromism • IR glasses: Chalcogenide, Fluorite glasses • Optical Fibers: Principle, Manufacturing, Applications, Photonic fibers |Vibrational spectroscopies, from theory to practice | • Nature of vibrations inside matter • Interaction light matter • Instrumentation • Raman application • Infrared Spectroscopy • Advanced technics
6	**Learning objectives and skills**	|Spectroscopy techniques applied to amorphous materials | The students will • Understand the solid state physic background link to the optical properties of all type of materials • Be able to explain the different ways to create colors • Choose the appropriate glass compositions to realize optical device in the infrared region • Have an overview of the different technologies link to light management • Know the different parameters that define an Optical glass fiber and choose them in regard of the attended application |Vibrational spectroscopies, from theory to practice| The student will • Understand in a comprehensive way the solid state physic background link to these spectroscopies

		• Know the different parts of a spectrometer and their characteristic parameter • Exercise himself to set the parameters of an observation and run the measurements • Treat the data by applying the needed corrections • Evaluate the data using peak fitting, momentum calculations and Principal Component Analysis • Deduce information on the structure of common glasses
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 46229	**Glas II** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Glass formulation using project management (2 SWS)	-
3	Lecturers	Prof. Dr. Dominique Ligny	

4	**Module coordinator**	Prof. Dr. Dominique Ligny
5	**Contents**	Glass formulation using project management: Intensive exercise of 6 half days at the end of the semester. The teaching follows an "on time approach. After presentation of the case study, an introduction to the project management is given. Analytical tools are given to the students than can use them directly on the case study. The project is then defined through brainstorming followed by Solution analysis and quotation. The rules for scheduling, monitoring and controlling a project are introduced before the case study is started to be solved. An emphasis is given on reporting by quick presentation at the end of each half day by the project team. In conclusion a last time is taken to analyze the personal issues encounter during these six half days. That help the students to have a pragmatic thinking about what could have been a better project team and the need of a leader. Glass and Ceramic for Energy-technology: • Materials and energy • Solar Energy • Solar Thermal • Photovoltaic Energy • Insulation • Wind Energy • Nuclear waste glass storage • Energy in glass processing • Fuel Cell and Ion conductivity • Lighting LED and LASER REE technology
6	**Learning objectives and skills**	Glass formulation using project management The student will • Learn the different concept used in project management as well as its specific vocabulary • Practice the project management in a small team • Use the different tools of project management • Go from an application to the conception of a product Glass and Ceramic for Energy-technology The student will • Understand the global environmental issues related to the use of glasses for: • Nonrenewable energy sources • Renewable energy sources • Energy efficiency • Energy storage • Know the improvement needed in the future

		• Look for solution by linking the expected performance to the glass properties • Be able to choose the good glass composition, production and shaping processes
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 48311	**Modern Optics 1: Advanced Optics** Modern optics 1: Advanced optics	**5 ECTS**
2	Courses / lectures	Übung: Modern Optics 1: Advanced Optics (Excercise class) (2 SWS) Vorlesung: Modern Optics 1: Advanced Optics (2 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Stephan Götzinger	

4	**Module coordinator**	Prof. Dr. Stephan Götzinger
5	**Contents**	Scalar wave optics: Maxwell equations, solutions to the wave equation, interference effects; Fourier optics: propagation in free space, through aperture and lenses, Fourier transformation in the far field; Vectorial wave optics: Maxwell equation and solution of the vectorial fields: Gaussian laser beam (fundamental and higher order modes), focusing of vector fields in free space, vector fields with optical angular momentum; Optics in waveguides: geometrical approach and Maxwell equation with boundary conditions, transverse modes, cutoff for planar waveguide, optical fibers, tapers, couplers; Whispering gallery mode resonators: modal description, applications.
6	**Learning objectives and skills**	Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	-

1	**Module name** 42140	**Optical Lithography: Technology, Physical Effects and Modeling**	**5 ECTS**
2	Courses / lectures	Vorlesung: Halbleitertechnologie IV - Optical Lithography: Technology, Physical Effects, and Modelling (2 SWS) Übung: Übung zu Halbleitertechnologie IV - Optical Lithography (2 SWS)	- -
3	Lecturers	PD Dr. Andreas Erdmann	

4	**Module coordinator**	PD Dr. Andreas Erdmann
5	**Contents**	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 aper-ture 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.
6	**Learning objectives and skills**	The goals of this lecture are 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
7	**Prerequisites**	• abgeschlossens Grundstudium / B.Sc. • Grundlagen der Optik und Elektotechnik
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222

		Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• 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.

1	**Module name** 46253	**Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Phosphors for Light Conversion in Photovoltaic Devices and LEDs (2 SWS) Praktikum: Lab Work Manufacturing and Characterization of Phosphors and Storage Phosphors (3 SWS)	3 ECTS 2,5 ECTS
3	Lecturers	PD Dr.Ing. Miroslaw Batentschuk Dr. Andres Osvet	

4	**Module coordinator**	PD Dr.Ing. Miroslaw Batentschuk
5	**Contents**	• Phosphors for Light Conversion in Photovoltaic Devices and LEDs (Im Wintersemester) (Vorlesung, 2 SWS, Miroslaw Batentschuk • Lab Work Manufacturing and Characterization of Phosphors and Storage Phosphors (im Sommersemester) (Praktikum, 3 SWS, Andres Osvet et al., Zeit n. V., Labore LS i-MEET)
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	Bachelor in Material Science, Nanotechnology, Energy Technology, Electronic Engineering, Computer Science, Physics, Chemistry, Chemical Engineering , Nanotechnologie, Energietechnik, Elektrotechnik, Physik, Chemie or comparable
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Verwendbarkeit des Moduls / Einpassung in den Musterstudienplan: 1) Materialwissenschaft und Werkstofftechnik (Master of Science) (Po-Vers. 2020w | TechFak | Materialwissenschaft und Werkstofftechnik (Master of Science) | Kernfach 1 | Materialien der Elektronik und der Energietechnologie | weitere Wahlmodule | Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management) 2) Materialwissenschaft und Werkstofftechnik (Master of Science) (Po-Vers. 2020w | TechFak | Materialwissenschaft und Werkstofftechnik (Master of Science) | Kernfach 2 und 3 | Materialien der Elektronik und der Energietechnologie | weitere Wahlmodule | Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management) 3) Materialwissenschaft und Werkstofftechnik (Master of Science) (Po-Vers. 2020w | TechFak | Materialwissenschaft und Werkstofftechnik (Master of Science) | 1. und 2. Wahlfach | Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management)

		Dieses Modul ist daneben auch in den Studienfächern "Nanotechnologie (Master of Science)" verwendbar. Details
10	**Method of examination**	Variable Studien-/Prüfungsleistungen: Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management (Prüfungsnummer: 62531) Prüfungsleistung, mündliche Prüfung, Dauer (in Minuten): 15, benotet, 5 ECTS Anteil an der Berechnung der Modulnote: 100.0 % weitere Erläuterungen: zusätzlich zur mündlichen Prüfung - unbenoteter Nachweis vom Praktikum Prüfungssprache: Englisch Erstablegung: SS 2022, 1. Wdh.: WS 2022/2023 weitere Erläuterungen: mögliche weitere Prüfungsformen sind Klausur (45 Min.) oder Hausarbeit benotet (ca. 20 Seiten) Oral examination, exercises, and report from lab work Prüfungssprache: Deutsch oder Englisch 1. Prüfer: Miroslaw Batentschuk, 2. Prüfer: Andres Osvet
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 40 h Independent study: 110 h
15	**Module duration**	2 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 42923	**Photovoltaic systems - Fundamentals** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Advanced Semiconductor Technologies - Photovoltaic Systems for Power Generation - Design Implementation and Characterization (2 SWS) Übung: Excercises Photovoltaic systems Fundamentals (CEP) (Ex-PVS-F) (3 SWS)	3 ECTS 2 ECTS
3	Lecturers	Prof. Dr. Christoph Brabec Dr. Jens Hauch Dr. Andres Osvet Dr. Karen Forberich	

4	**Module coordinator**	Prof. Dr. Christoph Brabec
5	**Contents**	The lecture will introduce to the fundamentals of photovoltaic energy conversion. The conversion of light into electricity is one of the most efficient power technologies of today and is expected to transform our energy system towards a renewable scenario. The limits of photovoltaic energy conversion, the materials and architectures of major PV technologies and advanced characterization methods for modules as well as solar fields will be introduced theoretically and experimentally during the lecture and exercices.
6	**Learning objectives and skills**	• The students will learn the concept of black body radiation and the radiation laws and the limits of light energy conversion. The fundamental semiconductor junctions (p-n, M-i-M, Shottky and Hetero Junction are repeated. The one diode and two diodes replacement circuits are explained . Electrical, optical, recombination and extraction loss mechanisms are discussed separately and demonstrated at the hand of numerical drift-diffusion equation solvers. The most important solar cell concepts (Si, CIGS, CdTe, GaAs, Perovksites, Organics) are introduced, and the strengths and weaknesses of each technology are analysed. • Characterization of Photovoltaic Modules will trained by flashed measurements in the lab. Defect imaging methods like DLIT, EL or PL imaging will be trained at the hand of module installations in Erlangen.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in winter semester

13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 75 h Independent study: 75 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• Will be provided via StudOn

1	**Module name** 67134	**Theoretical Methods for optical properties of solids** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Theoretical Methods for optical properties of solids (3 SWS)	5 ECTS
3	Lecturers		

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 44960	**Thermophysikalische Eigenschaften von Arbeitsstoffen der Verfahrens- und Energietechnik** Thermophysical properties of working materials in process and energy engineering	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Thermophysikalische Eigenschaften von Arbeitsstoffen der Verfahrens- und Energietechnik (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Thomas Manfred Koller Dr.-Ing. Tobias Klein Dr.-Ing. Michael Rausch Prof. Dr.-Ing. Andreas Paul Fröba Dr. Johannes Knorr	

4	**Module coordinator**	Dr.-Ing. Thomas Manfred Koller
5	**Contents**	• Bedeutung von Stoffdaten in der Verfahrens- und Energietechnik • Gleichgewichtseigenschaften zur Charakterisierung von Arbeitsstoffen, z.B. in Form der thermodynamischen Zustandseigenschaften und -größen Dichte, innere Energie, Enthalpie, Entropie, spezifische Wärmekapazität, Schallgeschwindigkeit, Brechungsindex, Oberflächen- und Grenzflächenspannung • Transporteigenschaften zur Charakterisierung des molekularen Masse-, Energie- und Impulstransportes, z.B. Viskosität, Diffusionskoeffizient, Soret-Koeffizient, Thermodiffusionskoeffizient, Wärme- und Temperaturleitfähigkeit • Anwendungsbezogene Stoffdatenrecherche in der wissenschaftlichen Literatur, Tabellenwerken und Datenbanken • Korrelationen und Vorhersagemethoden für Stoffeigenschaften • Methoden zur experimentellen Bestimmung und prozessbegleitenden Messung von Stoffdaten, insbesondere durch moderne laseroptische Techniken • Grundzüge der theoretischen Bestimmung von Stoffdaten mit Hilfe der molekularen Modellierung • Aufstellung von thermischen und kalorischen Zustandsgleichungen *Content* • The importance of thermophysical properties in process and energy engineering • Equilibrium properties for the characterization of working materials, e.g., in the form of thermodynamic properties of state and other equilibrium properties such as density, internal energy, enthalpy, entropy, specific heat capacity, sound speed, refractive index, surface or interfacial tension, etc. • Transport properties for the characterization of molecular transfer of mass, energy, and momentum, e.g. diffusion

		coefficients, Soret coefficient, thermal diffusion coefficient, thermal conductivity, thermal diffusivity, and viscosity • Use-oriented inquiry of thermophysical property data in scientific literature, table compilations, and databases • Correlation and prediction of thermophysical properties • Methods for experimental determination and in-process measurement of thermophysical properties, in particular by laser-optical techniques • Basics of the theoretical prediction of thermophysical properties by molecular modeling • Development of thermal and caloric equations of state
6	**Learning objectives and skills**	Die Studierenden • sind mit der Bedeutung von Stoffdaten in der Verfahrens- und Energietechnik in Form von Gleichgewichts- und Transporteigenschaften vertraut, • verwenden verschiedene Bezugsquellen für Stoffeigenschaften (Recherche in wissenschaftlicher Literatur, Tabellenwerken und Datenbanken; Korrelationen und Vorhersagemethoden; theoretische und experimentelle Bestimmung) eigenständig und wählen diese bedarfsgerecht und abhängig vom resultierenden Nutzen und Aufwand aus, • kennen die Herangehensweisen zur Korrelation und Vorhersage von Stoffeigenschaften sowie zur Aufstellung von thermischen und kalorischen Zustandsgleichungen und übertragen diese Herangehensweisen auf andere Stoffe, • sind mit experimentellen Methoden zur Stoffdatenbestimmung vertraut, insbesondere mit laseroptischen Messtechniken, • verstehen die Grundzüge der molekularen Modellierung zur theoretischen Bestimmung von Stoffdaten und • wählen Arbeitsmedien mit definierten Stoffeigenschaften für eine optimierte Gestaltung von Verfahren und Prozessen der Energie- und Verfahrenstechnik aus. *Education objectives and competences* The students • are aware of the importance of thermophysical properties in process and energy engineering in the form of equilibrium and transport properties, • use various sources for thermophysical properties (scientific literature, table compilations, databases, correlations, predictions, theoretical and experimental determination) independently and select the respective sources in a use-oriented way considering the resulting effort and benefit, • know the approaches for the correlation and prediction of thermophysical properties as well as for developing equations of state, and are able to transfer these approaches to other systems, • are familiar with experimental methods for the determination of thermophysical properties, in particular with laser-optical methods,

		• understand the basics of the use of molecular modeling for the theoretical determination of thermophysical properties, • select working materials with defined thermophysical properties for an optimized design of processes in energy and process engineering.
7	**Prerequisites**	Grundkenntnisse der Technischen Thermodynamik sowie der Wärme-, Stoff- und Impulsübertragung Basic knowledge on Engineering Thermodynamics as well as heat, mass, and momentum transfer
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• R. C. Reid, J. M. Prausnitz, B. E. Poling, The properties of gases and liquids, McGraw Hill Book Co., New York, 1987 • Recommended Reference Materials for the Realization of Physicochemical Properties, K. N. Marsh (ed.), Blackwell Scientific Publications, Oxford, 1987 • Measurement of the Transport Properties of Fluids, W. A. Wakeham, A. Nagashima, and J. V. Sengers (eds.), Blackwell Scientific Publications, Oxford, 1991 • R. Haberlandt, S. Fritzsche, G. Peinel, K. Heinzinger, Molekulardynamik: Grundlagen und Anwendungen, Vieweg, Braunschweig/Wiesbaden, 1995 • R. W. Kunz, Molecular Modelling für Anwender, Teubner, Stuttgart 1997 • M. J. Assael, J. P. M. Trusler, T. F. Tsooakis, Thermophysical Properties of Fluids, Imperial College Press, London, 1996 • Transport Properties of Fluids, J. Millat, J. H. Dymond, and C. A. Nieto de Castro (eds.), Cambridge University Press, Cambridge, 1996

		• J. M. Haile, Molecular Dynamics Simulation: Elementary Methods, John Wiley & Sons, Inc., Canada, 1997 • G. Grimvall, Thermophysical Properties of Materials, Elsevier, Amsterdam, 1999 • J. A. Wesselingh, R. Krishna, Mass Transfer in Multicomponent Mixtures, Delft University Press, Delft, The Netherlands, 2000 • Equations of State for Fluids and Fluid Mixtures, J. V. Sengers, R. F. Kayser, C. J. Peters, and H. J. White, Jr. (eds.), Elsevier, Amsterdam 2000 • Measurement of the Thermodynamic Properties of Single Phases, A. R. H. Goodwin, K. N. Marsh, and W. A. Wakeham (eds.), Elsevier, Amsterdam 2003 • Diffusion in Condensed Matter, P. Heitjans and J. Kärger (eds.), Springer, New York 2005 • R. B. Bird, W. E. Stewart, E. N. Lightfoot, Transport Phenomena, John Wiley & Sons, Inc., U.S.A., 2007 • C. L. Yaws, Thermophysical Properties of Chemicals and Hydrocarbons, William Andrew, Inc., Norwich, 2008 • Applied Thermodynamics of Fluids, A. R. H. Goodwin, J. V. Sengers, C. J. Peters (eds.), Elsevier, Amsterdam, 2010 • Experimental Thermodynamics Volume IX: Advances in Transport Properties of Fluids, M. J. Assael, A. R. H. Goodwin, V. Vesovic, and W. A. Wakeham (eds.), Royal Society of Chemistry, Cambridge, 2014

1	**Module name** 67145	**Waveguides, optical fibres and photonic crystal fibres**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Waveguides, optical fibres and photonic crystal fibres (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

Computational Optics

1	**Module name** 43220	**Computational Optics**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Computational Optics CE & MAOT (2 SWS)	7,5 ECTS
3	Lecturers	Prof. Dr. Christoph Pflaum	

4	**Module coordinator**	Prof. Dr. Christoph Pflaum
5	**Contents**	Simulation optischer Wellen Finite-Differenzen-Methode zur Lösung der Maxwellschen Gleichungen Strahl-Propagations-Methoden Ratengleichungen für Photonen Anwendung im Bereich der Simulation von Lasern und Dünnschichtsolarzellen
6	**Learning objectives and skills**	Fachkompetenz Anwenden Anwendung unterschiedlicher Simulationstechniken in der Optik Analysieren Analyse der Stabilität von Simulationstechniken Erschaffen Entwicklung von Software zur Simulation von optischen Wellen
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 43386	**Computational Photography and Capture** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Übung: Tutorials to Computational Photography and Capture (2 SWS) Vorlesung: Computational Photography and Capture (2 SWS)	- 5 ECTS
3	Lecturers	Vanessa Klein	

4	**Module coordinator**	Prof. Dr. Tim Weyrich
5	**Contents**	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
6	**Learning objectives and skills**	• o ... the basic vocabulary of computational photography • o ... principles of light transport in natural scenes o ... principles of digital image formation o ... how computational-photography algorithms can exploit knowledge of these principles to transcend the capabilities of traditional photograph • o ... image-processing algorithms to analyse and transform images o ... acquisition algorithms to capture appearances and 3D scene • o ... their own software prototypes to capture and process digital images
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (30 minutes)
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in summer semester

13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 713618	**Computer vision**	**5 ECTS**
2	Courses / lectures	Übung: Computer Vision Exercise (2 SWS) Vorlesung: Computer Vision (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Bernhard Egger Prof. Dr.-Ing. Andreas Maier Prof. Dr. Tim Weyrich	

4	**Module coordinator**	Prof. Dr. Bernhard Egger Prof. Dr.-Ing. Andreas Maier
5	**Contents**	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.
6	**Learning objectives and skills**	Die Vorlesung stellt eine Auswahl von Methoden aus dem Gebiet der Computer Vision vor, die in dem Feld eine zentrale Stellung einnehmen. In den Übungen implementieren und evaluieren die Studierenden selbständig diese Methoden. Die Studierenden arbeiten die ganze Zeit über an populären Computer Vision-Methoden wie zum Beispiel Stereosehen, optischer Fluss und 3D-Rekonstruktion aus mehreren Ansichten. Für diese Probleme • beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen, • erklären die Studierenden die behandelten Methoden, • diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen, • implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code, • entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme, • erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation, • diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen, • diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens. 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.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (90 minutes)
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.

1	**Module name** 42135	**Image Processing in Optical Nanoscopy** Image processing in optical nanoscopy	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Image Processing in Optical Nanoscopy (0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Harald Köstler	

4	**Module coordinator**	Prof. Dr. Harald Köstler
5	**Contents**	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.
6	**Learning objectives and skills**	• 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.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	The relevant scientific literature are current publications that are provided during the course.

1	**Module name** 44151	**Medical Image Processing for Diagnostic Applications**	**5 ECTS**
2	Courses / lectures	Vorlesung: Medical Image Processing for Diagnostic Applications (VHB-Kurs) (4 SWS)	5 ECTS
3	Lecturers	Manuela Meier Arpitha Ravi Luis Rivera Monroy	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	English version: 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. Deutsche Version: Die Inhalte des Moduls umfassen Grundlagen der medizinischen Bildverarbeitung und Aufnahmeprinzipien. Darüber hinaus werden Details der Vorverarbeitung für Bildverstärker, Flachpaneldetektoren und MR erklärt. Die Grundlagen der Rekonstruktion von Parallelstrahl bis hin zur Kegelstrahl-Tomographie werden ebenfalls behandelt. Im letzten Kapitel wird starre Registrierung für Bildfusion erläutert.
6	**Learning objectives and skills**	English Version: 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. Deutsche Version: Die Teilnehmenden • verstehen die Herausforderungen in der interdisziplinären Arbeit zwischen Ingenieuren und Ärzten. • entwickeln Verständnis für Algorithmen und Mathematik der diagnostischen medizinischen Bildverarbeitung. • erfahren, dass kreative Adaption von bekannten Algorithmen auf neue Probleme der Schlüssel für ihre berufliche Zukunft ist. • entwickeln die Fähigkeit Algorithmen auf verschiedene Probleme anzupassen. • sind in der Lage, Algorithmen und Konzepte des Moduls anderen Studierenden der Technischen Fakultät zu erklären.
7	**Prerequisites**	Ingenieurmathematik

8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 44141	**Medical Image Processing for Interventional Applications**	**5 ECTS**
2	Courses / lectures	Vorlesung: Medical Image Processing for Interventional Applications (VHB-Kurs) (4 SWS)	5 ECTS
3	Lecturers	Manuela Meier Arpitha Ravi Luis Rivera Monroy	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	English Version: 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. Deutsche Version: Das Modul ist auf die jüngsten Entwicklungen in der Verarbeitung von medizinischen Bildern ausgerichtet. Alle Algorithmen werden durch praktische Probleme motiviert. Die mathematischen Werkzeuge, die für die Bildverarbeitungsaufgaben benötigt werden, werden eingeführt. Das Modul beginnt mit einem Überblick über Vorverarbeitungsalgorithmen, wie zum Beispiel Streustrahlkorrektur für Röntgenbilder, Kantenerkennung, Superresolution und kantenerhaltende Rauschunterdrückung. Das zweite Kapitel beschreibt die automatische Bildanalyse mit Merkmalsdeskriptoren, Punkterkennung und Segmentierung mit Bottom-up-Algorithmen wie dem Random-Walker oder Top-Down-Ansätzen wie aktiven Formmodellen. Darüber hinaus deckt die Vorlesung auch geometrische Kalibrierungsalgorithmen zur Einzelansicht-Kalibrierung, Epipolargeometrie und Faktorisierung ab. Der letzte Teil des Moduls deckt nicht-starre Registrierung auf der Grundlage von Variationsmethoden und bewegungskompensierter Bildrekonstruktion ab.
6	**Learning objectives and skills**	English Version: 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. Deutsche Version: Die Teilnehmenden • fassen die Inhalte der Vorlesung zusammen. • wenden Vorverarbeitungsalgorithmen wie Streustrahlkorrektur und kantenerhaltende Filterung an. • extrahieren automatisch Informationen aus Bildern, indem sie Bildanalyseverfahren wie Punktdetektoren und Segmentierungsalgorithmen verwenden. • kalibrieren Projektionsgeometrien für Einzelbilder und Bildsequenzen mit den beschriebenen Methoden. • entwickeln nicht-starre Registrierungsmethoden mit Hilfe von Variationsrechnung und unterschiedlichen Regularisierern. • wenden Algorithmen auf neue Modalitäten durch entsprechende Änderungen im Algorithmus an.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 44120	**Pattern Analysis** Pattern analysis	**5 ECTS**
2	Courses / lectures	Vorlesung: Pattern Analysis (3 SWS) Übung: Pattern Analysis Programming (1 SWS)	3,75 ECTS 1,25 ECTS
3	Lecturers	PD Dr.Ing. Christian Riess Dalia Rodriguez Salas	

4	**Module coordinator**	PD Dr.Ing. Christian Riess
5	**Contents**	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 Das Modul führt in das Design von Musteranalysesystemen sowie die zugrundeliegenden mathematischen Methoden ein. Die Vorlesung umfasst im Einzelnen: • Clustering-Methoden: Soft- und Hard-Clustering • Klassifikations- und Regressionsbäume/-wälder • parametrische und nicht-parametrische Dichteschätzung: Verfahren sind ML- und MAP-Schätzung, Histogramme, Parzenschätzung, Zusammenhang gefaltete Histogramme und Parzenschätzung, adaptives Binning mit Regressionsbäumen. • 'Mean Shift'-Algorithmus: lokale Maximierung durch Gradientenaufstieg bei nicht-parametrischen Dichtefunktionen, Anwendungen des 'Mean Shift'-Algorithmus zum Clustering, Farbquantisierung und Objektverfolgung • Linear and Non-Linear Manifold Learning: Curse of Dimensionality, Verschiedene Methode zur

		Dimensionsreduktion: Principal Component Analysis (PCA), Multidimensionsional Scaling (MDS), Isomap, Laplacian Eigenmaps • Gaußsche Mischverteilungsmodelle (GMM) und Hidden-Markov-Modelle (HMM): 'Expectation Maximization'-Algorithmus, Parameterschätzung, Bestimmung der optimalen Zustandsfolge/Viterbi-Algorithmus, Vorwärts-Rückwärts-Algorithmus, Skalierung • Markov-Zufallsfelder: Definition, Wahrscheinlichkeiten auf ungerichteten Graphen, Cliquen-Potenziale, Hammersley-Clifford-Theorem, Inferenz mit Gibbs-Sampling und Graph Cuts
6	**Learning objectives and skills**	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. Die Studierenden • erläutern die behandelten Methoden zur Klassifikation, Vorhersage und Analyse von Mustern, • vergleichen und analysieren Methoden des Manifold Learning und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • vergleichen und analysieren Methoden zur Dichteschätzung und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • wenden nicht-parametrische Dichteschätzung auf Probleme der Musteranalyse an, • wenden Dimensionsreduktion bei hochdimensionalen Merkmalsräumen an, • erläutern statistische Modellierung von Merkmalsmengen und Merkmalsfolgen, • erklären statistische Modellierung abhängiger Größen,

		• implementieren vorgestellte Verfahren in Python. • ergänzen eigenständig mathematische Grundlagen der präsentierten Methoden durch selbstbestimmtes Studium der Literatur • diskutieren die gesellschaftlichen Auswirkungen von Anwendungen der Musteranalyse
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (60 minutes)
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	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

1	**Module name** 44130	**Pattern Recognition** Pattern recognition	**5 ECTS**
2	Courses / lectures	Übung: Pattern Recognition Exercises (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Siming Bayer Paul Stöwer	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	**Learning objectives and skills**	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an

		• beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	**Prerequisites**	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	
17	**Bibliography**	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009

		• Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	**Module name** 67156	**Quantum Computing** Quantum computing	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Computing (2 SWS) Übung: Quantum Computing - Übung (0 SWS) Übung: Quantum Computing (SWS)	5 ECTS - -
3	Lecturers	Prof. Dr. Michael Hartmann	

4	**Module coordinator**	Prof. Dr. Michael Hartmann
5	**Contents**	*Contents:* 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.
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	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 .

1	**Module name** 47643	**Seminar Advanced Algorithms in Medical Image Processing** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Seminar Advanced Deep Learning (2 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Vincent Christlein Prof.Dr.Ing. Katharina Breininger	

4	**Module coordinator**	Prof.Dr.Ing. Katharina Breininger Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Deep Learning-based algorithms showed great performance in many fields of image processing and pattern recognition and compete with technologies such as compressive sensing and iterative optimization. The basis for the success of these algorithms is the availability of large amounts of data (big data) for training and of high computing power (typically GPUs). In this seminar, we try to explore advanced deep learning methods. In particular, we will aim to develop a deeper understanding of certain topics, for example, graph neural networks, unsupervised learning, differentiable learning, invertible learning, neural ordinary differential equations, transfer learning, multi-task learning, uncertainty DL, etc.
6	**Learning objectives and skills**	Students will be able to • perform their own literature research on a given subject • independently research this subject • present and introduce the subject to their student peers • give a scientific talk in English according to international conference standards
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 93154	**Seminar Computer Vision** no english module name available for this module	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 47658	**Seminar: Digital Pathology and Deep Learning** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Seminar Digital Pathology and Deep Learning (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Samir Jabari Prof.Dr.Ing. Katharina Breininger	

4	**Module coordinator**	Prof.Dr.Ing. Katharina Breininger
5	**Contents**	Pathology is the study of diseases and aims to deliver a fine-grained diagnosis to understand processes in the body as well as to enable targeted treatment. In this area, the opportunities for digital image processing are vast: While the need for precision medicine, i.e., taking into account various co-dependencies when formulating the best possible treatment for a patient, is high, the number of pathologists ist not increasing accordingly. Deep learning-based techniques can be used for different objectives in this scope. Examples include screening large microscopy images for specific rare events, providing visual augmentation with analysis data. Additionally, the availability of massive data collections, including genomics and further biological factors, can be utilized to determine specific information about diseases that were previously unavailable. This seminar is offered to students of medicine as well as computer sciences and medical engineering and similar. Students will have to present a topic from this field in a short (30 min) and comprehensive presentation. List of topics: • Staining and special stains (including immunohistochemistry, enzyme-based dyes and tissue microarrays) • Current computational pathology • Knowledge/Feature fusion into a diagnosis • Histopathology quality control • Data sets as limiting factor - limits of current data sets • Large scale / clinical grade solutions • Computational and augmented tumor grading • In vivo microstructural analysis • Big data in pathology (multi-omics) • Histology image registration • Staining differences and stain normalization • Transfer learning and domain adaptation • Explainable AI • Virtual staining • Digital workflow in Germany vs. the world • Limits of digital pathology
6	**Learning objectives and skills**	Students will be able to • perform their own literature research on a given subject • independently research this subject • present and introduce the subject to their student peers

		• give a scientific talk in English according to international conference standards
7	**Prerequisites**	Students are required to have initial experience with deep learning and machine learning, e.g., from the module "Deep Learning". This seminar is recommended for Master's students.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (30 minutes)
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 47607	**Seminar Intraoperative Imaging and Machine Learning** no english module name available for this module	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof.Dr.Ing. Katharina Breininger
5	**Contents**	For many applications, techniques like deep learning allow for considerably faster algorithm development and allow to automate tasks that were performed manually in the past. In medical imaging, a large variety of time-consuming tasks that interfere with clinical workflows has the potential for automation. However, at the same time new challenges arise like data privacy regulations and ethics concerns. In this seminar, we want to develop an application that allows for the automation of an X-ray based intraoperative planning or measurement procedure from a holistic perspective. To this end, we will invite a surgeon to explain the medical background and visit the operating room to understand the surgeons needs while performing the task. Having understood the underlying medical problem, we will look into topics of data privacy, code of ethics, prototype development, and UI design for surgeons. Furthermore, we will touch regulatory requirements necessary for releasing software to clinics. At the end of the seminar, the students will have developed and documented a prototypical application for the indented intraoperative use case.
6	**Learning objectives and skills**	Students will be able to • visit an operation room, following the rules of such an environment • perform their own literature research on a given subject • independently research this subject according to data privacy and ethical standard • present and introduce the subject to their student peers • give a scientific talk in English according to international conference standards • describe their results in a scientific report
7	**Prerequisites**	Students are required to have initial experience with deep learning and machine learning, e.g., from the module "Deep Learning". This seminar is recommended for Master's students.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement

11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67171	**Simulationsmethoden in der Optik** Simulation methods in optics	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

Physics of Light

1	**Module name** 42155	**Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (4 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics)(Laser exercise lab)(EV-AL) (1 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (Excercise class) (2 SWS)	10 ECTS - -
3	Lecturers	Prof. Dr. Joachim Zanthier Prof. Dr. Stephan Götzinger	

4	**Module coordinator**	Prof. Dr. Joachim Zanthier
5	**Contents**	*Contents* 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
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written (120 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 42130	**Advanced Laser**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Advanced Laser (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly	

4	**Module coordinator**	Dr. Jürgen Grossmann Prof. Dr. Nicolas Joly
5	**Contents**	This module naturally follows the "Basics of Lasers module and aims at deepen the knowledge on a few specific aspects of lasers. In particular we will study the Z-cavity of one of the most popular laser system: the Titanium: sapphire laser. The purpose here is to show why simpler cavity is not possible. It requires understanding properly the concept of stability of laser cavity and introduces the problem of astigmatism. In a second stage we see how dispersion effects can hamper the properties of a mode-locked laser system and see how to circumvent this. We then study the different method used to characterize ultrashort laser pulse. This starts from basics concepts of autocorrelation but review more advanced techniques allowing to retrieve fully the amplitude and phase of a laser pulse. Towards the end of the lecture several topics are possible and it will be chosen together with the students. This can be for instance (i) the polarization and the Jones formalism (ii) the Maxwell-Bloch equations (iii) the origin of spontaneous emission. Finally in order to broaden the contents of the lecture the students are asked to prepare one half-an-hour presentation of the topics of their choice. The topics are discussed during the first two sessions of the lecture and must focus on a physical aspect of laser.
6	**Learning objectives and skills**	Students • Understand the problem of dispersion in a laser cavity and establish a strategy to balance this problem in order to achieve transform-limited ultrashort pulses • Estimate the duration of a laser pulse and adapt the technique to the level of precision required • Understand the design of laser cavities
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Material Processing Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)

11	**Grading procedure**	Oral (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• "Laser by A.E. Siegman, University Science book, 1986 • "Handbook of Lasers and Optics by F. Träger, Springer, 2007 • "Les lasers by D.Dangoisse, D. Hennequin and V. Zehnlé)Dhaoui, Dunod 1998 • "Principles of Lasers, 5th ed. by Orazio Svelto, Springer 2010 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

1	**Module name** 67143	**Advanced nonlinear optics** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced nonlinear optics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi	

4	**Module coordinator**	Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi Prof. Dr. Nicolas Joly
5	**Contents**	*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)
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h

15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 42190	**Modern Concepts in Optics** Modern concepts in optics	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (45 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 48313	**Modern Optics 3: Quantum Optics** Modern optics 3: Quantum optics	**5 ECTS**
2	Courses / lectures	Vorlesung: Modern Optics 3: Quantum Optics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Maria Chekhova	

4	**Module coordinator**	Prof. Dr. Maria Chekhova
5	**Contents**	**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
6	**Learning objectives and skills**	**Learning goals and competences:** Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral PL: oral examination 30 Min.
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	-

1	**Module name** 67008	**Nobel Prizes in Theory of Light and Matter** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Hauptseminar: Nobel Prizes in Theory of Light and Matter (SWS) Das Seminar findet in einem hybriden Format statt, d.h. sowohl im Seminarraum als auch via Zoom Zoom-Link: https://fau.zoom.us/j/3095185870	-
3	Lecturers	Prof. Dr. Kai Phillip Schmidt	

4	**Module coordinator**	Prof. Dr. Kai Phillip Schmidt
5	**Contents**	The nobel prize is the most prestigious award in physics. Here we focus on nobel prizes for the quantum theory of light and matter. This field is an important cornerstone of modern physics and the largest research pillar of our physics department. Goal of this seminar is to gain an understanding and overview of the most prominet topics in this field.
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (45 minutes)
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67127	**Nonlinear and Quantum Optics** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Hauptseminar: Physikalisches Seminar: Nonlinear and Quantum Optics (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Maria Chekhova Dr. Markus Sondermann	

4	**Module coordinator**	Prof. Dr. Maria Chekhova
5	**Contents**	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
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Will be provided individually for each talk.

1	**Module name** 582360	**Modern Optics 2: Nonlinear Optics** Nonlinear optics	**5 ECTS**
2	Courses / lectures	Vorlesung: Modern Optics 2: Nonlinear Optics (2 SWS)	-
3	Lecturers	Prof. Dr. Nicolas Joly Prof. Dr. Maria Chekhova	

4	**Module coordinator**	Prof. Dr. Nicolas Joly
5	**Contents**	*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.
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optical Metrology Master of Science Advanced Optical Technologies 20222 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	*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)

1	**Module name** 67009	**Novel techniques in ultrafast spectroscopy** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Seminar: Novel techniques in ultrafast spectroscopy (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Daniele Fausti Dr. Francesca Fassioli Olsen	

4	**Module coordinator**	Prof. Dr. Daniele Fausti
5	**Contents**	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/
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!

9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (45 minutes)
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Primary literature will be provided by the supervisors of the individual topics.

1	**Module name** 520257	**Polarization of light in classical, nonlinear, and quantum optics**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67188	**Quantum Communication** Quantum communication	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Communication (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Christoph Marquardt Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr. Christoph Marquardt
5	**Contents**	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
6	**Learning objectives and skills**	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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optics in Communication and IT Master of Science Advanced Optical Technologies 20182 Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Will be provided individually for each talk.

1	**Module name** 67156	**Quantum Computing** Quantum computing	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Computing (2 SWS) Übung: Quantum Computing - Übung (0 SWS) Übung: Quantum Computing (SWS)	5 ECTS - -
3	Lecturers	Prof. Dr. Michael Hartmann	

4	**Module coordinator**	Prof. Dr. Michael Hartmann
5	**Contents**	*Contents:* 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.
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Computational Optics Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	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 .

1	**Module name** 909727	**Quantum Magnetism, Spin Waves, and Light** Quantum magnetism, spin waves, and light	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 745913	**Quantum Physics of Light-Matter Interactions** Quantum physics of light-matter interactions	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67165	**Seminar: Modern Optics: Recent trends in nonlinear optics, classical and quantum optics**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (45 minutes)
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67134	**Theoretical Methods for optical properties of solids** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Theoretical Methods for optical properties of solids (3 SWS)	5 ECTS
3	Lecturers		

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Materials and Systems Master of Science Advanced Optical Technologies 20182 Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

Physics of Light

1	**Module name** 66941	**Advanced experimental physics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (4 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics)(Laser exercise lab)(EV-AL) (1 SWS) Übung: Advanced Course in Experimental Physics (Lasers, Atomic Physics and Quantum Optics) (Excercise class) (2 SWS) Vorlesung: Advanced experimental physics: Solid state physics (4 SWS) Vorlesung: Advanced experimental physics: Particle and astroparticle physics (4 SWS) Übung: Advanced experimental physics: Solid state physics (Exercise class) (3 SWS) Übung: Advanced experimental physics: Particle and astroparticle physics (Excercise class) (3 SWS)	10 ECTS - - 10 ECTS 10 ECTS - -
3	Lecturers	Prof. Dr. Joachim Zanthier Prof. Dr. Stephan Götzinger Prof. Dr. Heiko Weber Prof. Dr. Stefan Funk	

4	**Module coordinator**	Prof. Dr. Stefan Funk Prof. Dr. Ana-Suncana Smith Prof. Dr. Christopher van Eldik Prof. Dr. Joachim Zanthier
5	**Contents**	**Course Advanced Experimental Physics: Lasers, Atomic Physics and Quantum Optics (EV-A)** • 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
- Introduction to non-linear optics: Introduction to quantum optics, Hanbury-Brown-Twiss experiment, quantum nature of light, photon correlations, photon statistics, examples of non-classical light, bunching und antibunching of photons, resonance fluorescence

Course Advanced Experimental Physics: Particla and Astroparticle Physics (EV-B)

- Introduction: Interactions and exchange bosons, Feynman diagrams; relativistic kinematics with four- vectors
- Covariant description of spin-less particles: Free particles, spatial probability density, charge current density, equation of continuity; Klein-Gordon equation: Solutions for free particles, energy eigenvalues, interpretation by Feynman and Stückelberg; scattering on a static potential: Perturbative approach, transition matrix element, Fermi's Golden Rule
- Electrodynamics of spin-1/2 particles: Maxwell equations in covariant notation; Dirac equation (free particles, gamma matrices, spin, anti-particles, helicity, charge current density, equation of continuity); electron- muon scattering: Current-current interaction, photon propagator, Feynman rules, helicity conservation, spin averaging (without explicit calculation), differential cross section; electron-positron annihilation to muons or quarks, hadron/muon ratio R; decay width and its relation to matrix element and phase space factor; higher orders: Anomalous magnetic moment (g-2), charge renormalisation, running coupling constant
- Weak interactions: Charged current: (V-A) structure and parity violation, propagator, Fermi constant, quark mixing: Cabibbo angle, CKM matrix, its complex phase and CP violation, direct and indirect CP violation; massive neutrinos; Oscillations, PMNS matrix, oscillation phenomenology of solar, atmospheric and reactor neutrinos
- Neutral currents and electroweak unification: Weak isospin and hypercharge, SU(2)xU(1); electroweak coupling: Weinberg angle, Z- fermion-couplings
- Gauge theories and Higgs mechanism: Euler-Lagrange equation, global gauge invariance and current conservation: local gauge invariance and QED: Mass and interaction terms, photon field, spontaneous U(1) symmetry breaking; Higgs mechanism for U(1): Gauge freedom, Higgs mass

		and interaction terms, masses of U(1)xSU(2) gauge bosons (without explicit derivation); Higgs coupling to Standard Model particles, Higgs production and decay **Course Advanced Experimental Physics: Solid State Physics (EV-C)** • Crystal structures • Structure determination • Vibrational properties • Electronic structure • Electronic transport • Dielectric and optical properties • Magnetism • Superconductivity
6	**Learning objectives and skills**	**Course Advanced Experimental Physics: Lasers, Atomic Physics and Quantum Optics (EV-A)** 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 **Course Advanced Experimental Physics: Particle and Astroparticle Physics (EV-B)** Students • explain and analyze advanced experimental topics of particle and astroparticle physics as outlined in the table of contents • apply the associated physical concepts to specific problems using appropriate methods **Course Advanced Experimental Physics: Solid State Physics (EV-C)** • explain and analyze advanced experimental topics of solid state physics as outlined in the table of contents • apply the associated physical concepts to specific problems using appropriate methods
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222

10	**Method of examination**	Written or oral
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	only in winter semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 210 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 66961	**Advanced theoretical physics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced theoretical physics: Solid state physics (4 SWS) Übung: Advanced theoretical physics: Advanced quantum mechanics (Exercise class) (3 SWS) Übung: Advanced theoretical physics: Solid state physics (Exercise class) (3 SWS) Vorlesung: Advanced theoretical physics: Advanced quantum mechanics (4 SWS)	10 ECTS - - 10 ECTS
3	Lecturers	Prof. Dr. Ana-Suncana Smith Prof. Dr. Kristina Giesel	

4	**Module coordinator**	Prof. Dr. Kristina Giesel Prof. Dr. Hanno Sahlmann Prof. Dr. Ana-Suncana Smith
5	**Contents**	**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, thermal properties, anharmonic effects • Electrons in a periodic potential: Bloch theorem, band structure, nearly free electrons, tight-binding method, Wannier functions, metals, insulators, semiconductors, density of states, Fermi surface, quantum statistics, thermal properties, Fermi distribution • Electron-electron interaction: Hartree-Fock method, density functional theory, homogeneous electron gas • Topics of current research
6	**Learning objectives and skills**	**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
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 105 h Independent study: 195 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	no Bibliography information available!

1	**Module name** 44445	**Cognitive Neuroscience for AI Developers** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Cognitive Neuroscience for AI Developers (4 SWS)	5 ECTS
3	Lecturers	Dr. rer. nat. Achim Schilling Prof. Dr. Andreas Kist Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	
5	**Contents**	Neuroscience has played a key role in the history of artificial intelligence (AI), and has been an inspiration for building human-like AI, i.e. to design AI systems that emulate human intelligence. Neuroscience provides a vast number of methods to decipher the representational and computational principles of biological neural networks, which can in turn be used to understand artificial neural networks and help to solve the so called black box problem. This endeavour is called neuroscience 2.0 or machine behaviour. In addition, transferring design and processing principles from biology to computer science promises novel solutions for contemporary challenges in the field of machine learning. This research direction is called neuroscience-inspired artificial intelligence. The course will cover the most important works which provide the cornerstone knowledge to understand the biological foundations of cognition and AI, and applications in the areas of AI-based modelling of brain function, neuroscience-inspired AI and reverse-engineering of artificial neural networks.
6	**Learning objectives and skills**	The students • Explain the principles of neural information processing in the brain • compare and analyze methods from neuroscience to study neural networks • explain the neuroscientific underpinnings of artificial intelligence • explain principles and concepts of cognitive science • explain principles and concepts of neuroscience • compare and analyze machine learning methods to analyze neural data • explain approaches from deep learning to model brain function • discuss the commonalities of neuroscience and artificial intelligence • implement the presented methods in Python • explain concepts from cognitive neuroscience for the design of artificial intelligence systems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182

		Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	Gazzaniga, Michael. Cognitive Neuroscience - The Biology of the Mind. W. W. Norton & Company, 2018. Ward, Jamie. The Student's Guide to Cognitive Neuroscience. Taylor & Francis Ltd., 2019. Bermúdez, José Luis. Cognitive Science: An Introduction to the Science of the Mind. Cambridge University Press, 2014. Friedenberg, Jay D., and Silverman, Gordon W. Cognitive Science: An Introduction to the Study of Mind. SAGE Publications, Inc., 2015. Gerstner, Wulfram, et al. Neuronal dynamics: From single neurons to networks and models of cognition. Cambridge University Press, 2014.

1	**Module name** 901895	**Deep Learning** Deep learning	**5 ECTS**
2	Courses / lectures	Vorlesung: Deep Learning (2 SWS) Übung: Deep Learning Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Andreas Maier Zijin Yang Alexander Barnhill	

4	**Module coordinator**	Felix Denzinger Prof. Dr.-Ing. Andreas Maier Fabian Wagner
5	**Contents**	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.
6	**Learning objectives and skills**	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.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• 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)

1	**Module name** 65718	**Introduction to Machine Learning** Introduction to machine learning	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Introduction to Machine Learning (2 SWS) Übung: Introduction to Machine Learning Exercises (2 SWS) Übung: Introduction to Machine Learning Tutorial (2 SWS)	5 ECTS 1,25 ECTS -
3	Lecturers	Dr.-Ing. Vincent Christlein Paul Stöwer	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Die Vorlesung hat zum Ziel, die Studierenden mit dem prinzipiellen Aufbau eines Mustererkennungssystems vertraut zu machen. Es werden die einzelnen Schritte von der Aufnahme der Daten bis hin zur Klassifikation von Mustern erläutert. Die Vorlesung beginnt dabei mit einer kurzen Einführung, bei der auch die verwendete Nomenklatur eingeführt wird. Die Analog-Digital-Wandlung wird vorgestellt, wobei der Schwerpunkt auf deren Auswirkungen auf die weitere Signalanalyse liegt.Im Anschluss werden gebräuchliche Methoden der Vorverarbeitung beschrieben. Ein wesentlicher Bestandteil eines Mustererkennungssystems ist die Merkmalsextraktion. Verschiedene Ansätze zur Merkmalsberechnung/-transformation werden gezeigt, darunter Momente, Hauptkomponentenanalyse und Lineare Diskriminanzanalyse.Darüber hinaus werden Möglichkeiten vorgestellt, Merkmalsrepäsentationen direkt aus den Daten zu lernen.Die Vorlesung schließt mit einer Einführung in die maschinelle Klassifikation. In diesem Kontext wird der Bayes- und der Gauss-Klassifikator besprochen.
6	**Learning objectives and skills**	Die Studierenden • erklären die Stufen eines allgemeinen Mustererkennungssystems • verstehen Abtastung, das Abtasttheorem und Quantisierung • verstehen und implementieren Histogrammequalisierung und -dehnung • vergleichen verschiedene Schwellwertmethoden • verstehen lineare, verschiebungsinvariante Filter und Faltung • wenden verschiedene Tief- und Hochpassfilter sowie nichtlineare Filter an • wenden verschiedene Normierungsmethoden an • verstehen den Fluch der Dimensionalität • erklären verschiedene heuristische Merkmalsberechnungsmethoden, z.B. Projektion auf einen orthogonalen Basisraum, geometrische Momente, Merkmale basierend auf Filterung • verstehen analytische Merkmalsberechnungsmethoden, z.B. Hauptkomponentenanalyse, Lineare Diskriminanzanalyse • verstehen die Basis von Repräsentationslernen

		• erläutern die Grundlagen der statistischen Klassifikation (Bayes-Klassifikator) • benutzen die Programmiersprache Python, um die vorgestellten Verfahren der Mustererkennung anzuwenden • lernen praktische Anwendungen kennen und wenden die vorgestellten Algorithmen auf konkrete Probleme an
7	**Prerequisites**	Ein Mustererkennungssystem besteht aus den folgenden Stufen: Aufnahme von Sensordaten, Vorverarbeitung, Merkmalsextraktion und maschinelle Klassifikation. Diese Vorlesung beschäftigt sich in erster Linie mit den ersten drei Stufen und schafft damit die Grundlage für weiterführende Lehrveranstaltungen (Pattern Recognition und Pattern Analysis).
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• Vorlesungsfolien • Heinrich Niemann: Klassifikation von Mustern, 2. überarbeitete Auflage, 2003 • Sergios Theodoridis, Konstantinos Koutroumbas: Pattern Recognition, 4. Auflage, Academic Press, Burlington, 2009 • Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2. Auflage, John Wiley & Sons, New York, 2001

1	**Module name** 95068	**Machine Learning for Engineers II: Advanced Methods** no english module name available for this module	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning for Engineers II: Advanced Methods (0 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Björn Eskofier Thomas Altstidl	

4	**Module coordinator**	Thomas Altstidl Prof. Dr. Björn Eskofier
5	**Contents**	This is an advanced course with a focus on deep learning (DL) techniques that are typically applied to data science problems. Knowledge is deepened by two practical exercises to gain hands-on experience. The course covers • Extended introduction into fundamental concepts of deep neural networks (DNN) • In-depth review of various optimization techniques for learning neural network parameters • Specification of several regularization techniques for neural networks • Theoretical understanding of application-specific neural network architectures (such as convolutional neural networks (CNN) for images and recurrent neural networks (RNN) for time series)
6	**Learning objectives and skills**	After successfully participating in this course, students should be able to • discuss advantages and disadvantages of different optimization techniques • design a suitable and promising neural network architecture and train it on existing data using Python and Keras • choose a suitable regularization technique in case of problems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 75 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english

17	**Bibliography**	1) Machine Learning: A Probabilistic Perspective, Kevin Murphy, MIT Press, 2012 2) The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Trevor Hastie, Robert Tibshirani, and Jerome Friedman, Springer, 2009 3) Deep Learning, Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, 2016

1	**Module name** 95067	**Machine Learning for Engineers I - Introduction to Methods and Tools** no english module name available for this module	**5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning for Engineers I: Introduction to Methods and Tools (0 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Björn Eskofier Thomas Altstidl Prof. Dr. Nico Hanenkamp Prof. Dr.-Ing. Jörg Franke	

4	**Module coordinator**	Thomas Altstidl Prof. Dr. Björn Eskofier
5	**Contents**	This is an introductary course presenting fundamental algorithms of machine learning (ML) that are typically applied to data science problems. Knowledge is deepened by two practical exercises to gain hands-on experience. The course covers • Introduction to Python programming in the field of data science • Review of typical task domains (such as regression, classification and dimensionality reduction) • Theoretical understanding of widely used machine learning methods (such as linear and logistic regression, support vector machines (SVM), principal component analysis (PCA) and deep neural networks (DNN)) • Practical application of these machine learning methods on engineering problems
6	**Learning objectives and skills**	After successfully participating in this course, students should be able to • independently recognize the task domain at hand for new applications • select a suitable and promising machine learning methodology based on their known theoretical properties • apply the chosen methodology to the given problem using Python
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 semester

16	**Teaching and examination language**	english
17	**Bibliography**	1) Machine Learning: A Probabilistic Perspective, Kevin Murphy, MIT Press, 2012 2) The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Trevor Hastie, Robert Tibshirani, and Jerome Friedman, Springer, 2009 3) Deep Learning, Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, 2016

1	**Module name** 668977	**Machine Learning for Physicists** Machine learning for physicists	**5 ECTS**
2	Courses / lectures	Hauptseminar: Machine Learning for Physicists (PW-ML) (2 SWS) Übung: Machine Learning for Physicists (UE) (SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Florian Marquardt	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 67172	**Methods of Data Analysis I** Methods of data analysis I	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Anna Nelles
5	**Contents**	The lectures provide an overview of the most important methods for the statistical evaluation of measured data. It lays the foundation for bachelor and master theses in experimental physics. In the first part of the lectures we will deal with the basics of statistics and probability theory. The second part of the lectures provides an introduction to measurement error and error calculation, parameter estimates and confidence intervals. For some of the exercises we will use computer (python language), which will be useful for the data analysis in the context of a Bachelor / Master thesis. The topics will include: Part I. Probability and statistics • Introduction to statistics and probability theory • Special distibutions: Gaussian, Poisson, Multinomial • Parameter estimators of the distribution (mean, variance, bias etc.) • Multi-dimensional distributions • Random sampling Part II. Statistical interpretation of measurements • Least squared method • Chi2 fitting • Maximal likelihood • Bayesian statistics • Estimation of confidence intervals • Binned and unbinned analysis
6	**Learning objectives and skills**	*Learning goals and competences:* Students • explain the relevant topics of the lecture • apply the methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Unregelmäßig
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	W. J. Metzger: "Statistical Methods in Data Analysis" Roger J. Barlow: "Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences", ISBN-10: 0471922951

1	**Module name** 903776	**Seminar Machine Learning and Data Analytics for Industry 4.0** Seminar machine learning and data analytics for industry 4.0	**5 ECTS**
2	Courses / lectures	Seminar: Maschinelles Lernen und Datenanalytik für Industrie 4.0 (2 SWS) Attendance of all meetings is required.	5 ECTS
3	Lecturers	Prof. Dr. Björn Eskofier Johannes Roider Christoph Scholl	

4	**Module coordinator**	Prof. Dr. Björn Eskofier An Nguyen Johannes Roider
5	**Contents**	Companies in all kinds of industries are producing and collecting rapidly more and more data from various sources. This is enabled by technologies such as the Internet of Things (IoT), Cyber-physical systems (CPS) and cloud computing. Hence, there is an increasing demand in industry and research for students and graduates with machine learning and data analytics skills in the Industry 4.0 context. The goal of this seminar is to give students insights about state-of-the-art machine learning and data analytics methods for industrial and business applications. In this seminar, the Industry 4.0 term will not only be limited to manufacturing processes, but comprise all business functions. Students will mainly work independently on either an implementation-centric or a research-centric topic. The implementation-centric topics will focus primarily on the implementation of algorithms and analytical components (using provided or open source datasets), while the research-centric topics will focus on researching and structuring literature of a specific field of interest. Several topics will be provided, but students are also encouraged to propose their own topics when applying for the seminar. In the regular meetings, students will learn about fundamentals and trends in Industry 4.0 from a machine learning perspective, common machine learning techniques and their implementation, project management of data analytics projects in businesses, as well as best practices for presentations and scientific work. The programme will be complemented by talks from invited experts in the domain. Furthermore, students will present results from literature research and data analytics projects.
6	**Learning objectives and skills**	• Students will develop an understanding of the current hot field of machine learning and data analytics in businesses • Students will learn to research and present a topic within the context of machine learning and data analytics in businesses independently • Students will learn to identify opportunities, challenges and limitations of corresponding ML approaches in businesses

		• Students will develop the skill to identify and understand relevant literature and to present their findings in a structured manner • Students will learn to present implementation and validation results in form of a demonstration and/or report
7	**Prerequisites**	• Prior knowledge of machine learning via courses like Pattern Analysis, Pattern Recognition, Deep Learning, Machine Learning for Time Series, or equivalent is expected. Alternatively, first data science project experience, for example as working student in a company, can be sufficient. • Motivation to explore scientific findings (e.g. via literature research) • Motivation to code and analyze data
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%) • 50% of grade: Presentation (20 minutes) • 50% of grade: 4 pages IEEE standard paper (excluding references) (+ code submission)
12	**Module frequency**	every semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	• Lei, Yaguo, Naipeng Li, Liang Guo, Ningbo Li, Tao Yan, and Jing Lin. "Machinery Health Prognostics: A Systematic Review from Data Acquisition to RUL Prediction. Mechanical Systems and Signal Processing 104 (May 2018): 799834.https://doi.org/10.1016/j.ymssp.2017.11.016. • Rojas, Eric, Jorge Munoz-Gama, Marcos Sepúlveda, and Daniel Capurro. "Process Mining in Healthcare: A Literature Review. Journal of Biomedical Informatics 61 (June 1, 2016): 22436. https://doi.org/10.1016/j.jbi.2016.04.007. • Wil M. P. van der Aalst. Process Mining: Data Science in Action 2nd edition, Springer 2016. ISBN 978-3-662-49851-4 • Wang, Lihui, and Xi Vincent Wang. Cloud-Based Cyber-Physical Systems in Manufacturing. Cham: Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-67693-7.

1	**Module name** 47675	**Seminar Meta Learning** no english module name available for this module	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20182 Free Modules Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? semester (no information for Module duration available)
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!

1	**Module name** 66190	**Theoretische Physik 3: Quantenmechanik** Theoretical physics 3: Quantum mechanics	**10 ECTS**
2	Courses / lectures	Vorlesung: Theoretische Physik 3: Quantenmechanik (4 SWS) Übung: Übungen zu Theoretische Physik 3: Quantenmechanik (SWS)	10 ECTS -
3	Lecturers	Prof. Dr. Michael Hartmann	

4	**Module coordinator**	Prof. Dr. Hanno Sahlmann
5	**Contents**	• Mathematische Grundlagen: Hilbertraum, Lineare Operatoren, Spektren von Operatoren, Selbstadjungierte Operatoren • Grundlagen der Quantenmechanik: Zustände, Observablen, Messwerte, Unschärferelation, S Interpretation • Schrödinger-Gleichung: Stationäre Lösungen, Freies Teilchen, Eindimensionale Potentiale, Heisenberg-Bild, Ehrenfesttheorem • Harmonischer Oszillator: Algebraische Methode, Erzeugungs- und Vernichtungsoperatoren, Berechnung des Spektrums und der Eigenfunktionen • Wasserstoffatom: Eigenfunktionen der gebundenen Zustände. Spektrum des Wasserstoffatoms. Orbitale des Wasserstoffatoms • Drehimpuls und Spin: Drehimpuls- und Spinoperatoren, Eigenfunktionen des Drehimpulses, Kopplung von Drehimpulsen • Näherungsmethoden: Zeitunabhängige Störungstheorie
6	**Learning objectives and skills**	Die Studierenden • erläutern und erklären die theoretisch-physikalische Beschreibung der Quantenmechanik und reflektieren vorgestellte Theorien gemäß den detaillierten Themen im Inhaltsverzeichnis • strukturieren Probleme mathematisch und lösen sie eigenständig
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Free Modules Master of Science Advanced Optical Technologies 20182 Physics of Light Master of Science Advanced Optical Technologies 20182 Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (120 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	only in summer semester
13	**Resit examinations**	The exams of this moduls can only be resit once.

14	**Workload in clock hours**	Contact hours: 105 h Independent study: 195 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german
17	**Bibliography**	no Bibliography information available!