Friedrich-Alexander-Universität Erlangen-Nürnberg

Module description

for the degree programme

Master of Science Advanced Optical Technologies

(Version of examination regulation: 20222)

for the summer term 2025

Table of contents

1	**Module name** 1999	**Master's thesis (M.Sc. Advanced Optical Technologies 20222)** Master’s thesis	**30 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**	The students - independently pursue a scientific question of the corresponding subject area over a longer period of time and work on it within a given time limit. (Focus on self-competence/subject competence) - develop independent ideas and concepts to solve scientific scientific problems. (Focus on methodological competence/specialist competence) - deal with theories, terminologies, special features, limits and doctrines of the subject in an in-depth and critical manner and reflect on them. and reflect on them. (Focus on professional competence/self-competence) - apply and further develop appropriate scientific methods largely independently - also in new and unfamiliar as well as interdisciplinary contexts. (Focus methodological competence). - can present subject-related content clearly and appropriately to the target group in writing (and, if necessary, orally) and defend it argumentatively. (focus on social competence/specialist competence) - expand their planning and structuring abilities in the implementation of a thematic project. (focus on metho- dical competence/specialized competence). Please adapt the competencies to the professional requirements or expand them accordingly. Please note that theses written at other universities or in similar courses of study must be credited if they are equivalent. A precise module description helps to make the process of credit transfer (also the decision of non-credit transfer) transparent and to facilitate it for all parties involved.
6	**Learning objectives and skills**	The students - independently pursue a scientific question of the corresponding subject area over a longer period of time and work on it within a given time limit. (Focus on self-competence/subject competence) - develop independent ideas and concepts to solve scientific scientific problems. (Focus on methodological competence/specialist competence) - deal with theories, terminologies, special features, limits and doctrines of the subject in an in-depth and critical manner and reflect on them. and reflect on them. (Focus on professional competence/self-competence)

		- apply and further develop appropriate scientific methods largely independently - also in new and unfamiliar as well as interdisciplinary contexts. (Focus methodological competence). - can present subject-related content clearly and appropriately to the target group in writing (and, if necessary, orally) and defend it argumentatively. (focus on social competence/specialist competence) - expand their planning and structuring abilities in the implementation of a thematic project. (focus on metho- dical competence/specialized competence). Please adapt the competencies to the professional requirements or expand them accordingly. Please note that theses written at other universities or in similar courses of study must be credited if they are equivalent. A precise module description helps to make the process of credit transfer (also the decision of non-credit transfer) transparent and to facilitate it for all parties involved. •
7	**Prerequisites**	Students must have earned 80 ECTS in order to register the master's thesiss
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) Written or oral (6 Monate)
11	**Grading procedure**	Oral (10%) Written or oral (90%)
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: 900 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	german or english
17	**Bibliography**	Depends on the subject of the thesis.

1	**Module name** 1996	**Internship (M.Sc. Advanced Optical Technologies 20222)** Internship	**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**	Course achievement Students have to submit the confirmation that they have done the internship and write a small report about their activities (2-3 pages). The internship is not graded.
11	**Grading procedure**	Course achievement (pass/fail) Not graded
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 0 h Independent study: 200 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	

1	**Module name** 1994	**Project report (M.Sc. Advanced Optical Technologies 20222)** Project report	**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**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	The student undertake a research project of about 300 h and write a project report about it 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**	Students learn how to • plan and carry out a research project • collect data and analyse them • present results in a structured report Students get prepared for writing the more comprehensive report of 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 Report of about 15-25 pages
11	**Grading procedure**	Written assignment (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 0 h Independent study: 300 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Depends on the subject of the report.

1	**Module name** 42101	**Fundamentals of Optics**	**15 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Paul Fröba
5	**Contents**	• A Brief History • Wave Motion: One-Dimensional Waves, Harmonic Waves, Phase and Phase Velocity, Superposition Principle, Complex Representation, Plane Waves, Three-Dimensional Wave Equation, Spherical Waves, Cylindrical Waves • Electromagnetic Theory, Photons, and Light: Farady's Induction Law, Gauss's Law, Ampère's Circuital Law, Maxwell's Equations, Transverse Waves, Energy and Momentum, Averaging Harmonic Functions, Radiance and Irradiance, The Inverse Square Law, Photon Counting, Radiation Pressure and Momentum, Electric Dipole, Light in Bulk Matter, Dispersion, The Electromagnetic-Photon Spectrum, • The Propagation of Light: Rayleigh Scattering, Scattering and Interference, The Transmission of Light Through Dense Media, Transmission and the Index of Refraction, Reflection, Refraction, Huygens's Principle, Fermat's Principle, Electromagnetic Approach, Fresnel Equations, Total Internal Reflection, Evanescent Wave, Optical Properties of Metals, Stokes Treatment of Reflection and Refraction, Photons, Waves, and Probability, Quantum Electrodynamics, • Geometrical Optics: Lenses, Refraction at Spherical Surfaces, Thin Lenses, Finite Imagery, Thin Lens Combinations, Apertures and Field Stops, Entrance and Exit Pupils, Relative aperture and f-Number, Mirrors, Prisms, Fiberoptics, Human eye, Magnifying Glasses, Compound Microscop, Camera, Telescope, Wavefront Shaping, Thick Lenses and Lens Systems, Analytical Ray Tracing, Aberrations, • Superposition of Waves: Addition of Waves, Standing Waves, Anharmonic Periodic Waves, Nonperiodic Waves, • Polarization: The Nature of Polarized Light, Polarizers, Dichroism, Birefringence, Polarization by Reflection, Retarders, Optical Modulators, Mathematical Description, • Interference: Conditions for Interference, Temporal and Spatial Coherence, Holographic Interferometry, The Fresnel-Arago Laws, Young's Experiment, Wavefront-splitting Interferometers, Dielectric Films – Double-Beam Interference, Michelson Interferometer, Mach-Zehnder Interferometer, • Diffraction: The Huygens-Fresnel Principle, Fraunhofer and Fresnel Diffraction, Several Coherent Oscillators, Fraunhofer

		Diffraction, Fresnel Diffraction, Kirchhoff's Scalar Diffraction Theory
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**	Eugen Hecht: Optics

1	**Module name** 42105	**Basics of Laser**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
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. During lab exercises the students will work on 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)

		At the end of the course there is a written exam (90 min). In addition the students have to write reports about two lab sessions.
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** 42110	**Numerical Methods and Topics in Optical Technologies**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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 (part "Numerical...) • 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 (part "Topics...") • 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**	Course achievement Students have to • produce two presentations (15-25 page) about two of the seven majors as a group work (in groups of 4-6 students) • do several small Matlab exercises (1-2 pages code) and a more comprehensive project (4-7 pages) Both achievements are not graded.
11	**Grading procedure**	Course achievement (pass/fail)
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**	Scripts and / or further literature will be distributed during the courses.

Optical Metrology

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	PD Dr. Thomas Manfred Koller Dr.-Ing. Tobias Klein Dr.-Ing. Michael Rausch Prof. Dr.-Ing. Andreas Paul Fröba	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Paul Fröba PD Dr. 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**	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 mündliche Prüfung zum Stoff von Vorlesung und Übung oral examination based on the contents of lectures and exercises
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** 45370	**Produktanalyse** Product analysis	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) benotete mündliche Prüfung 30 min
11	**Grading procedure**	Oral (100%) Prüfungsnote entspricht Modulnote
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 english
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** 45730	**Optical Technologies in Life Science** Optical technologies in life science	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	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**	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 (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**	• 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** 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. Christoph Marquardt	

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**	The students will be able • to derive the equations yielding the conversion efficiency of a nonlinear process based on either chi-2 or chi-3 material • to properly choose the right type of material for the best conversion efficiency in case of second-harmonic, sum-frequency or different frequency • to calculate the phase-matching condition that yields efficient nonlinear effect either using a crystal or an optical fibre • to design a parametric amplifier, phase-sensitive or phase insensitive; • to use nonlinear optical effects for the frequency conversion.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	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** 46228	**Glas I** Glass I	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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 Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable derzeit mündliche Prüfung (15 Min.) currently taking an oral exam (15 min.)
11	**Grading procedure**	Variable (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**	

1	**Module name** 42935	**Optical diagnostics in energy and process engineering**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	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) • Inelastic (Raman) scattering (species concentration, temperature, diffusion) • Incandescence (thermal radiation, temperature fields, pyrometry, particle sizing) • Velocimetry (flow fields, velocity) • Absorption spectroscopy (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 Biological Engineering, Mechanical Engineering, Life Science Engineering, Energy Technology, Computational Engineering) can participate.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable „Die Prüfung richtet sich nach dem didaktischen Charakter des Moduls und umfasst entweder eine mündliche Prüfung von 30 min oder eine Klausur von 90 min Dauer. Die Entscheidung für eine Prüfungsform wird in Semestern, in denen die Lehrveranstaltungen stattfinden, spätestens zwei Wochen nach Vorlesungsbeginn **in der Lehrveranstaltung und in der StudOn-Gruppe** bekannt gegeben. In Semestern, in denen keine Lehrveranstaltungen stattfinden, wird die Prüfungsform spätestens zwei Monate vor der Wiederholungsprüfung **in der StudOn-**Gruppe bekannt gegeben.“ “The examination depends on the didactic character of the module and comprises either an oral examination of 30 minutes or a written examination of 90 minutes. In semesters in which the courses take place, the decision on the type of examination will be announced in the course and in the StudOn group no later than two weeks after the start of lectures. In semesters in which no courses take place, the type of examination will be announced in the StudOn group no later than two months before the re-examination.”
11	**Grading procedure**	Variable (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**	• Lecture Slides • Hanson, R.K., Spectroscopy and Optical Diagnostics for Gases, Springer, 2016 • Bräuer, A: In situ Spectroscopic Techniques at High Pressure, Amsterdam 2015

1	**Module name** 67009	**Novel techniques in ultrafast spectroscopy**	**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. 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**	semester: 1
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**	Irregular
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** 48311	**Modern Optics 1: Advanced Optics** Modern optics 1: Advanced optics	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	The students will get exposed to more advanced optical topics ranging from thin periodic layers, optical cavities and waveguides to optical fibers, plasmonics, metamaterials, angular momentum of light and modern microscopy techniques. They will also apply newly introduced methods to specific examples.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) PL: Oral examination 30 min.
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**	Christopher Foot: Atomic physics

			Saleh Teich: Fundamentals of Photonics Mark Fox: Quantum Optics: an introduction

1	**Module name** 94474	**Photon & Neutron Scattering for Structure Determination** Photon & neutron scattering for structure determination	**5 ECTS**
2	Courses / lectures	Übung: Photon & Neutron Scattering for Structure Determination Exercises (1 SWS) Vorlesung: Photon & Neutron Scattering for Structure Determination (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Michael Engel PD Dr. Alberto Leonardi	

4	**Module coordinator**	PD Dr. Alberto Leonardi
5	**Contents**	The course aims to provide a comprehensive framework for investigation of chemical systems exploiting advanced photon and neutron scattering methods. Control of chemical and physical processes with atomic scale and fast time-resolution requires use of large-scale sources. Moreover, combination of numerical simulations with experiments is inevitable for designing of new materials and chemical processes. The objective of this course is for the student to learn: (i) what technologies are available for research and industry from international laboratories, (ii) how to access these resources, (iii) how numerical simulations can be used for data analysis. **Part I: Theory (30%)** **Basics** - Review of Materials crystal structure - X-ray – Matter interactions (absorption and elastic/inelastic scattering; Auger, etc.) - Scattering Theory (scattering by electron, atom, cell; scattering cross section; form factors) **Commercial vs. Large Scale Sources** - High energy X-ray and Neutrons (basic properties of X-rays vs. neutrons) - Synchrotron vs. X-ray free-electron-laser vs. neutron (radiation production) - Neutron - Matter interactions (scattering of neutrons; nuclear and magnetic scattering) - Access routes to Large Scale Facilities (project proposal, application process) **Part II: Investigation Techniques (40%)** **Photon scattering for the study of chemical processes** - Synchrotron techniques in catalytic science (XRPD, XPDF, XAFS) - Synchrotron techniques for Nanomaterials and Soft Matter Research (SAXS, XPCS) - In situ/operando synchrotron-based X-ray techniques (XRPD, XPDF, XAS, Imaging) **Neutron scattering for the study of biological systems** - Structure solution of macromolecular systems (SANS) - Macromolecular crystallography (NMX, Single Crystal Diffraction) - Neutron reflectometry (NR)

		Virtual Experiments - Data based simulation (e.g., Debye scattering equation) - Instrument based simulation (e.g., MC ray-tracing) **Part III: Applications (30%)** **Study of condensed matter systems - case study** - Mechanism of Crystallization (and growth) of polymers - Spatial and temporal exploration of heterogeneous catalysts. - Study of electrode materials in electrochemical cells during operation (e.g., battery) **Study of bio-organic systems - case study** - Study of water systems, hydroxyl groups, hydronium ions, etc. - Study of domain mixing - Study of membrane protein structure - Study of hydration and protonation states - Studies of oxidized and reduced forms of the protein Note: the discussion of the subjects during the course may not reflect the sequential order in the outline due to practical reasons (as an example applications are luckily to be presented in direct relation to the corresponding techniques and not as an independent segment of the course).
6	**Learning objectives and skills**	Students will become familiar with technologies available for industry and research applications at international laboratories, and discuss possibilities, limitations and future developments. Students who successfully participate in this module can: - Understand how scattering techniques are used for characterization of molecular systems, and understand the different type of source (e.g., laboratory X-ray, Synchrotron, Neutron and Neutron TOF) - Apply simulations to support the analysis of neuron and synchrotron scattering data - Identify investigation method and instrument by assessment of material and technique properties. - Collect information on topics of current interest and present the results to the course members orally or in writing - Explain how to access international laboratory resources, and how to support their experimental project proposals.
7	**Prerequisites**	Fundamentals of general physics
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Metrology Master of Science Advanced Optical Technologies 20222

10	**Method of examination**	Variable
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Only in summer semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	• B. E. Warren, "X-Ray Diffraction", Dover Publications Inc. (1990), ISBN: 978-0486663173 • B. D. Cullity, S. R. Stock, "Elements of X-Ray Diffraction", PRENTICE HALL, ISBN: 978-0201610918 • A.-J. Dianoux, G. Lander, “Neutron Data Booklet" Institute Laue-Langevin (2003), ISBN: 0-9704143-7-4 • Silvia D. S., "Elementary scattering theory for X-ray and neutron users", Oxford University Press (2011). ISBN: 0-19-100477-4 • Squires G. L., "Introduction to the Theory of Thermal Neutron Scattering", Cambridge University Press (2012). ISBN: 9781107644069 • Als-Nielsen J. & McMorrow D., "Elements of Modern X-ray Physics", John Wiley and Sons (2011). ISBN: 9780470973950 • Waseda Y., "X-Ray Diffraction Crystallography: Introduction, Examples and Solved Problems", Springer (2011) Berlin Heidelberg. ISBN: 9786613081940 • Willmott, P., "An Introduction to Synchrotron Radiation: Techniques and Applications", Wiley (2011) New York. ISBN: 9780470745786 • International Tables of Crystallography

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**	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**	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	**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 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

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 students • understand the principles of optical projection lithography • understand how optical and material-driven resolution enhancements work • get an introduction to Extreme Ultraviolet (EUV) lithography • get an overview on alternative lithographic techniques • get an introduction to computational lithography • discuss the role of nanoscale light scattering effects
7	**Prerequisites**	• Basics of optics and electrical engineering
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	PD 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**	Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (120 minutes) Mehrfachantwort-Multiplechoice-Verfahren, schriftlich 90 min
11	**Grading procedure**	Variable (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**	german
16	**Bibliography**	- Gregor Honsel, Rapid Manufacturing - Lee Goldmann, Principles of CT and CT Technology

		- Okoshi, Three-Dimensional Imaging Techniques

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**	Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Portfolio • In order to pass the course, all participants are supposed to write a short paper (approx. 6-8 pages) on an assigned subject (60% weight with respect to the overall grade) and give a presentation (approx. 12 minutes) based on this paper (40% weight with respect to the overall grade. • As the circumstances require the oral presentation may be held in a digital manner (e.g. using ZOOM videochat).
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**	

1	**Module name** 95360	**Lasersystemtechnik I: Hochleistungslaser für die Materialbearbeitung: Bauweisen, Grundlagen der Strahlführung und –formung, Anwendungen** Laser system technology I: High-power lasers for material processing: designs, basics of beam guidance and shaping, applications	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	Optical Material Processing Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral mündliche Prüfung, Dauer (in Minuten): 20
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**	

1	**Module name** 97150	**Lasertechnik / Laser Technology** Laser technology	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	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**	

1	**Module name** 97283	**Lasersystemtechnik II: Lasersicherheit, Integration von Lasern in Maschinen, Steuerungs- und Automatisierungstechnik** Laser system technology II: Laser safety, integration of lasers in machines, control and automation technology	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Lasersicherheit, Integration von Lasern in Maschinen, Steuerungs- und Automatisierungstechnik (2 SWS)	2,5 ECTS
3	Lecturers	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**	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

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**	Repetition of important topics of optics • Scattering of light • Basics of laser tissue interaction • Diagnostics applications of Light and lasers • Therapeutics applications of light and lasers • Theoretical and practical exercises
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**	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 (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**	

Lab courses major topic 1+2

1	**Module name** 42725	**Lab course: Optics in Medicine** Laboratory course: Optics in medicine	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Sebastian Schürmann
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**	Lab courses Major Topic 1+2 Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Course achievement
11	**Grading procedure**	Course achievement (pass/fail)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	

1	**Module name** 42730	**Lab course: Physics of Light** Laboratory course: Physics of light	**2,5 ECTS**
2	Courses / lectures	Praktikum: Physikalisches Fortgeschrittenenpraktikum (Mini) für Nebenfächler (3 SWS)	2,5 ECTS
3	Lecturers	Dr. Matthias Weißer	

4	**Module coordinator**	Dr. Matthias Weißer
5	**Contents**	The course offers the following experiments of which students conduct two: • Intefereometry, Coherence and Fourier Spectroscopy • Optical and electrical properties of microstructured semiconductors • Speckle • Photon statistics • Characterization of rectangular microwave cavities • Diode-pumped YAG Laser
6	**Learning objectives and skills**	After the course students • know how to conduct a scientific experiments • know how to analyse the data of a scientific experiment • know how to write a report about a scientific experiment
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Lab courses Major Topic 1+2 Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Course achievement
11	**Grading procedure**	Course achievement (pass/fail)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 105 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german or english
16	**Bibliography**	Will be distributed during the course depending on the selected experiments

Optics in Medicine

1	**Module name** 42145	**Photonics in Medical Engineering**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Florian Klämpfl
5	**Contents**	• Repetition of Important Topics of Optics • Light Sources for Medical Engineering • Optical components and systems for medical engineering • Diagnostics with Photonics • Therapeutics with Photonics • Production of Medical devices with Photonics
6	**Learning objectives and skills**	The students can explain optical topics being in particular important for medical engineering The students can explain the design and function of light and laser sources being important for medical applications The students comprehend the design and function of optical components, systems and devices being important for medical engineering The students can apply different approaches to model optical systems The students can apply different mathematical methods and approachs to analyse optical systems The students can explain selected applications of photonics in medical engineering The students can analyze paraxial optical systems The students can analyze problems in the field of photonics in medical engineering
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 (90 minutes)
11	**Grading procedure**	Written (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**	

1	**Module name** 45730	**Optical Technologies in Life Science** Optical technologies in life science	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	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**	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 (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**	• 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**	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** 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**	Repetition of important topics of optics • Scattering of light • Basics of laser tissue interaction • Diagnostics applications of Light and lasers • Therapeutics applications of light and lasers • Theoretical and practical exercises
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**	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 (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**	

1	**Module name** 47664	**Fundamentals in Anatomy and Physiology for Engineers** Fundamentals in anatomy and physiology for engineers	**5 ECTS**
2	Courses / lectures	Online-Kurs: Fundamentals in Anatomy and Physiology for Engineers (4 SWS) **For more information, please join the StudOn course.**	-
3	Lecturers	Benedikt Kleinsasser Prof. Dr. Dr. h. c. 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**	Optics in Medicine Master of Science Advanced Optical Technologies 20222 Written exam (on-site), 60 min.
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** 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 - Exercise (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
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 (120 minutes)
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**	

1	**Module name** 122337	**Magnetic Resonance Imaging** Magnetic resonance imaging	**5 ECTS**
2	Courses / lectures	Übung: Magnetic Resonance Imaging 1 - Übung (2 SWS)	2,5 ECTS
		Vorlesung: Magnetic Resonance Imaging 1 (2 SWS)	2,5 ECTS
3	Lecturers		

4	**Module coordinator**	Prof. Dr. Frederik Bernd Laun
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 (120 minutes)
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**	

1	**Module name** 47624	**Photonics in Medical Technology** Photonics in medical technology	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Dr.-Ing. Florian Klämpfl
5	**Contents**	• Selected Topics of Optics • Light Sources for medical applications and medical engineering • Optical components and systems for medical engineering • Photonics in Diagnostics • Photonics in Therapeutics
6	**Learning objectives and skills**	• The students can explain optical topics being in particular important for medical engineering • The students can explain the fundamentals, design and function of light and laser sources being important for medical applications • The students can explain the design and function of optical components, systems and devices being important for medical engineering • The students can explain the fundamentals of the light tissue-interaction process. • The students can explain selected applications of photonics in medical engineering and healthcare • The students can analyze problems in the field of photonics in healthcare • The students can use international (English) professional terminology correctly.
7	**Prerequisites**	The course targets senior Bachelor and Master students who are interested in gaining knowledge about photonics in healthcare. We strongly suggest profound knowledge in fundamentals of optics.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable Klausur, 90 min.
11	**Grading procedure**	Variable (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**	

1	**Module name** 746003	**Bild am Dienstag - Medizin in Röntgenbildern** Find the disease Case based teaching	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Bild am Dienstag - Medizin in Röntgenbildern (1 SWS)	-
3	Lecturers		

4	**Module coordinator**	apl. Prof. Dr. Rolf Matthias Janka Prof. Dr. Michael Uder
5	**Contents**	Anhand von aktuellen Fällen werden interaktiv Röntgenbilder, Computertomographien, MR-Tomographien und Ultraschalluntersuchungen analysiert und Tipps für die Befundung gegeben. Oft werden dabei typische Differenzialdiagnosen mit ähnlichen Veränderungen gezeigt oder weitere Fälle mit der gleichen Erkrankung. Ein Fall wird niemals zweimal gezeigt. Die Fälle bauen nicht aufeinander auf, so dass man jederzeit in die Vorlesung einsteigen kann.
6	**Learning objectives and skills**	Die Studierenden erkennen häufig vorkommende Erkrankungen mittels moderner Bildgebung.
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 Klausur, 60 min.
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 15 h Independent study: 60 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	german
16	**Bibliography**	

1	**Module name** 67094	**Biophysics of Cellular Building Blocks**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module! Absence at max. 2 seminar days.	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr. Vahid Sandoghdar Dr. Katja Zieske
5	**Contents**	• The topics for the presentations will be distributed in the first lecture (17. April 2024) • In the first part of this seminar Dr. Zieske will give lectures to introduce participants to the biological content of this seminar. The seminar also includes a session about scientific presentation and critical thinking in biophysics. [This gives participants at least one month of preparation time for their presentations.] • o Fluorescence and fluorescent labeling of cellular building blocks o Confocal microscopy o Optical tweezers o Single molecule tracking methods (iScat, TIRF microscopy) o Photolithography and microfluidics o Photoresponsive hydrogels • Possible seminar topics (cellular building blocks and their biophysical properties): • Liquid-liquid protein condensates • Biophysics of the cellular cytoskeleton (actin) • Biophysics of the cellular cytoskeleton (microtubuli) • Lipid membranes • Light-switchable protein domains • Min protein self-organization
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**	Optics in Medicine Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement presentations of 30 minutes, active participation in discussions
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h

		Independent study: 120 h
14	**Module duration**	?? semester (no information for Module duration available)
15	**Teaching and examination language**	
16	**Bibliography**	

Optics in Communication

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**	Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination PL: oral examination 30 Min.
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: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	-

1	**Module name** 67143	**Advanced nonlinear optics**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi Prof. Dr. Nicolas Joly
5	**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**	The student will be able • to choose the most appropriate optical fibre (microstructured or not, solid-core or gas-filled hollow-core) for generating a supercontinuum or pair of sidebands for a dedicated experiment • to design the appropriate tapered optical fibre to obtain an efficient nonlinear process • to use nonlinear optical effects for generating non-classical light, such as photon pairs or squeezed light; • to understand how nonlinear optics works at nanoscale.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular

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**	

1	**Module name** 67145	**Waveguides, optical fibres and photonic crystal fibres**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	1) Fundamental of waveguides (Guidance mechanism, modes and dispersion, geometrical and electromagnetic approach) 2) Photonic crystal fibres (PCF) 3) Nonlinear optics in PCF (soliton, supercontinuum generation, nonlinear optics in gases in hollow-core PCF) 4) Optical communication systems (system outline, waveguide components, transmission effects, performance limitations) 5) Optical fibre sensors: fibre sensing principles, waveguide-based sensing component, distributed sensing, sensor, network, sensor signal processing)
6	**Learning objectives and skills**	The students will be able • to identify a particular type of microstructure fibre for a dedicated experiment • to calculate the mode content supported by a specific fibre and model the modal properties • to evaluate the potential limitations of an optical fibre due to nonlinear effects • to choose the appropriate fibre (dispersion and nonlinearity) to generate quiet or very broad supercontinuum spectral using a photonic crystal fibre • to choose the appropriate type of fibre-based sensor according to the signal to probe • \to understand the performance limitation of the telecommunications systems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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 (30 minutes)
11	**Grading procedure**	Oral (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**	

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**	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**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Will be provided individually for each talk.

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	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**	Optics in Communication 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**	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** 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. Christoph Marquardt	

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**	The students will be able • to derive the equations yielding the conversion efficiency of a nonlinear process based on either chi-2 or chi-3 material • to properly choose the right type of material for the best conversion efficiency in case of second-harmonic, sum-frequency or different frequency • to calculate the phase-matching condition that yields efficient nonlinear effect either using a crystal or an optical fibre • to design a parametric amplifier, phase-sensitive or phase insensitive; • to use nonlinear optical effects for the frequency conversion.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	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** 621649	**Advanced Optical Communication Systems** Advanced optical communication systems	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	**Recommended Prerequisites:** • Fundamentals in signals and systems. • Basic knowledge of fiber optics and optoelectronic components recommended.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) Examinbation: oral exam (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: 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** Arduino hardware and software for lab applications and beyond	**2,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	The students gain 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**	semester: 1
9	**Module compatibility**	Optics in Communication Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written (60 minutes)
11	**Grading procedure**	Written (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 0 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Programming Arduino: Getting Started with Sketches *by Simon Monk*, ISBN 978-1259641633

1	**Module name** 67092	**Introduction to Quantum Communication** Introduction to quantum communication	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Introduction to 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**	**Inhalt:** • Introduction to quantum communication: Motivation and practical impact Introduction and refresh of fundamentals of quantum mechanics Basics of information theory Definition of a quantum state in quantum optics Fundamental principle of quantum key distribution Fundamental principle of quantum communication (classical and quantum capacity) Detailed steps of quantum key distribution Security proofs (epsilon security) Modulation of quantum states Detection of quantum states Electronics for coherent communication Error correction codes Practical implementations Combination with classical cryptography Fiber-based systems Free space and satellite-based systems Quantum repeaters
6	**Learning objectives and skills**	The students are learning the foundations of modern quantum communication and study concrete examples of quantum communication protocols. They should be able to quantitatively solve fundamental problems and understand scientific articles in the field. The lecture will introduce the foundations and aspects of implementation of quantum key distribution protocols. It will introduce experimental requirements and real-world applications and highlight interfaces to classical communication and cryptography.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Optics in Communication 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) 1)
11	**Grading procedure**	Written examination (100%)

12	**Module frequency**	Irregular
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**	

1	**Module name** 67212	**Methods in theoretical quantum optics**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Methods in theoretical quantum optics (4 SWS)	5 ECTS
3	Lecturers	PD Dr. Andrea Aiello	

4	**Module coordinator**	PD Dr. Andrea Aiello
5	**Contents**	The goal of this course is to furnish the students the main conceptual and calculation tools, used in typical theoretical research projects in quantum optics. These tools include operators algebra at increasing level of complexity for the study of single- and multimode states of the electromagnetic field, elementary concepts of group theory, some probability and random variable theory, and functional methods in quantum optics (mainly functional derivatives and path integration).
6	**Learning objectives and skills**	At the end of the lectures the students will be able to read and understand theoretical research papers in quantum optics, and to apply the learned concepts to their own future research.
7	**Prerequisites**	The course is targeted to MSc students since the main topic is "advanced quantum optics". It is assumed that students were already exposed to the quantization of the electromagnetic field. However, only knowledge of the elementary quantization of the transverse field in the Coulomb gauge is required to understand the lectures.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Computational Optics 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
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**	• The quantum theory of light, by Rodney Loudon, Oxford University Press • Optical Coherence and Quantum Optics, by Leonard Mandel and Emil Wolf, Cambridge University Press

		• Fundamental of Quantum Optics, by John R. Klauder and E. C. G. Sudarshan, Dover Publications, Inc. • Methods in theoretical Quantum Optics, by Stephen M. Barnett, and Paul M. Radmore, Oxford Science Publications In addition, lecture notes will be provided.

1	**Module name** 67211	**Quantum Information Processing: Implementations**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Information Processing: Implementations	-
3	Lecturers	Prof. Dr. Christopher Eichler	

4	**Module coordinator**	Prof. Dr. Christopher Eichler
5	**Contents**	Keywords: Introduction to experimental systems for quantum information processing (QIP). Quantum bits. Quantum Computing. Coherent Control. Measurement. Decoherence. Microscopic and macroscopic quantum systems. Trapped Ions, Rydberg Atoms, Photons, Quantum Dots, NV centers, Superconducting Circuits. During the past 20 years quantum physics has entered the domain of information technology in increasingly profound ways. Rapid progress in the physical sciences and in engineering and technology has allowed us to build information processing devices, which utilize the laws of quantum physics. In these processors information is stored in quantum states rather than classical states. As such the the superposition principle and entanglement can be exploited as new resources for processing, storing and protecting information. Information processors using quantum physics are expected to become potentially more powerful than their classical counterparts. Developments in this research field are driven by academic labs, startups and major industrial cooporations. The goal of this course is to provide a thorough introduction to physical implementations pursued in current research for realizing quantum information processors. The field of quantum information science is one of the fastest growing and most active domains of research in modern physics. Introduction to experimental systems for quantum information processing (QIP). - Quantum bits - Coherent Control - Measurement - Decoherence - DiVincenzo criteria QIP with - Ions - Superconducting Circuits - Photons - NMR - Rydberg atoms - NV-centers - Quantum dots

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**	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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	

Optical Materials and Systems

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**	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**	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	**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 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

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 students • understand the principles of optical projection lithography • understand how optical and material-driven resolution enhancements work • get an introduction to Extreme Ultraviolet (EUV) lithography • get an overview on alternative lithographic techniques • get an introduction to computational lithography • discuss the role of nanoscale light scattering effects
7	**Prerequisites**	• Basics of optics and electrical engineering
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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** 42155	**Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Joachim Zanthier
5	**Contents**	*Contents* • º 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
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**	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	**Workload in clock hours**	Contact hours: 105 h Independent study: 195 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Christopher Foot: Atomic physics Saleh Teich: Fundamentals of Photonics Mark Fox: Quantum Optics: an introduction

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	PD Dr. Thomas Manfred Koller Dr.-Ing. Tobias Klein Dr.-Ing. Michael Rausch Prof. Dr.-Ing. Andreas Paul Fröba	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Paul Fröba PD Dr. 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**	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 mündliche Prüfung zum Stoff von Vorlesung und Übung oral examination based on the contents of lectures and exercises
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** 46257	**Advanced Semiconductor Technologies Photovoltaic Systems I - Fundamentals** Advanced semiconductor technologies - Photovoltaic systems I - Fundamentals	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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 , or comparable
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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)

		Examination performance, oral examination, duration (in minutes): 15, graded, 5 ECTS Share in the calculation of the module grade: 100.0% Alternative examination forms: written exam (90 min). Choice of the examination form is done on the basis of the didactic character of the module. The decision for the examination form will be communicated: • in semesters where the lecture takes place: no more than two weeks after lecture start in the lecture and in the StudOn group • in semesters without lecture: at least two weeks before the repetition exam in the StudOn group
11	**Grading procedure**	Variable (100%) Advanced Semiconductor Technologies – Photovoltaic Systems I - Fundamentals (examination number: 62571) Share in the calculation of the module grade: 100.0 %
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 40 h Independent study: 110 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 67145	**Waveguides, optical fibres and photonic crystal fibres**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Nicolas Joly Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	1) Fundamental of waveguides (Guidance mechanism, modes and dispersion, geometrical and electromagnetic approach) 2) Photonic crystal fibres (PCF) 3) Nonlinear optics in PCF (soliton, supercontinuum generation, nonlinear optics in gases in hollow-core PCF) 4) Optical communication systems (system outline, waveguide components, transmission effects, performance limitations) 5) Optical fibre sensors: fibre sensing principles, waveguide-based sensing component, distributed sensing, sensor, network, sensor signal processing)
6	**Learning objectives and skills**	The students will be able • to identify a particular type of microstructure fibre for a dedicated experiment • to calculate the mode content supported by a specific fibre and model the modal properties • to evaluate the potential limitations of an optical fibre due to nonlinear effects • to choose the appropriate fibre (dispersion and nonlinearity) to generate quiet or very broad supercontinuum spectral using a photonic crystal fibre • to choose the appropriate type of fibre-based sensor according to the signal to probe • \to understand the performance limitation of the telecommunications systems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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 (30 minutes)
11	**Grading procedure**	Oral (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**		

1	**Module name** 48311	**Modern Optics 1: Advanced Optics** Modern optics 1: Advanced optics	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	The students will get exposed to more advanced optical topics ranging from thin periodic layers, optical cavities and waveguides to optical fibers, plasmonics, metamaterials, angular momentum of light and modern microscopy techniques. They will also apply newly introduced methods to specific examples.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) PL: Oral examination 30 min.
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**	Christopher Foot: Atomic physics

			Saleh Teich: Fundamentals of Photonics Mark Fox: Quantum Optics: an introduction

1	**Module name** 46228	**Glas I** Glass I	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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 Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable derzeit mündliche Prüfung (15 Min.) currently taking an oral exam (15 min.)
11	**Grading procedure**	Variable (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**	

1	**Module name** 46229	**Glas II** Glass II	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Glass and Ceramic for Energy-Technology (2 SWS)	-
3	Lecturers		

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 Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable derzeit mündliche Prüfung (15 Min.) currently taking an oral exam (15 min.)
11	**Grading procedure**	Variable (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**	

1	**Module name** 42923	**Photovoltaic systems - Fundamentals**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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 Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable Prüfungsform: Klausur (45 Minuten), benotet Written exam (45 minutes, graded)
11	**Grading procedure**	Variable (100%) The exam counts 100%
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 75 h Independent study: 75 h
14	**Module duration**	1 semester

15	**Teaching and examination language**	english
16	**Bibliography**	• Will be provided via StudOn

1	**Module name** 46253	**Photovoltaics (PV) and PV Systems II: Light Conversion and Light Management** Photovoltaics (PV) and PV Systems II: Light conversion and light management	**5 ECTS**
2	Courses / lectures	Vorlesung: Phosphors for Light Conversion in Photovoltaic Devices and LEDs (2 SWS, WiSe 2025) Praktikum: Lab Work Manufacturing and Characterization of Phosphors and Storage Phosphors (3 SWS, SoSe 2025)	3 ECTS 2,5 ECTS
3	Lecturers	Miroslaw Batentschuk	

4	**Module coordinator**	Miroslaw Batentschuk
5	**Contents**	The module consists of a lecture and a lab course: • 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) ; Scope: 1 experiment, 20 pages report. Contents: • Classification of phosphors according to their principle of operation and by field of application. • Establishing the relationships between crystal structure of phosphors as well as their composition and the desirable absorption and emission properties. • Energy transfer between the crystal lattice and active ions as well as between these ions • Consideration of several examples • Theoretical analysis of phosphor engineering with the purpose to reach maximal energy efficiency during transformation of the ionizing radiation • Basics and to methods of storage phosphor manufacturing • Analysis of requirements to the properties and new trends in development of phosphors for white light emitting diodes and for adaptation of the sun light spectrum to the sensitivity of solar cells and plants
6	**Learning objectives and skills**	• The students will get the theoretical background and the ability to determine the required parameters for engineering new phosphors as a part of photovoltaic modules and devices for modern lighting. • The students will be trained in processing of phosphors and dielectric layers. The students will gain knowledge in characterization of phosphors and improved solar cells.
7	**Prerequisites**	• Bachelor in Material Science, • Bachelor in Nanotechnologie / Nanotechnology,

		• Bachelor in Energietechnik / Energy Technology, • Bachelor in Elektrotechnik / Electronic Engineering, • Bachelor in Computer Science, • Bachelor in Physik / Physics, • Bachelor in Chemie / Chemistry • Bachelor in Chemical Engineering • or comparable
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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, Bericht 20 Seiten 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	**Workload in clock hours**	Contact hours: 40 h Independent study: 110 h
14	**Module duration**	2 semester
15	**Teaching and examination language**	english
16	**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. Christoph Marquardt	

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**	The students will be able • to derive the equations yielding the conversion efficiency of a nonlinear process based on either chi-2 or chi-3 material • to properly choose the right type of material for the best conversion efficiency in case of second-harmonic, sum-frequency or different frequency • to calculate the phase-matching condition that yields efficient nonlinear effect either using a crystal or an optical fibre • to design a parametric amplifier, phase-sensitive or phase insensitive; • to use nonlinear optical effects for the frequency conversion.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	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** 67143	**Advanced nonlinear optics**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi Prof. Dr. Nicolas Joly
5	**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**	The student will be able • to choose the most appropriate optical fibre (microstructured or not, solid-core or gas-filled hollow-core) for generating a supercontinuum or pair of sidebands for a dedicated experiment • to design the appropriate tapered optical fibre to obtain an efficient nonlinear process • to use nonlinear optical effects for generating non-classical light, such as photon pairs or squeezed light; • to understand how nonlinear optics works at nanoscale.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular

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**	

1	**Module name** 46222	**Keramische Werkstoffe: Prozessierung und Eigenschaften** Ceramic materials: Processing and properties	**5 ECTS**
2	Courses / lectures	Übung: Processing of Ceramics (1 SWS, SoSe 2025) Vorlesung mit Übung: Functional and Optical Properties of Glass and Ceramics (2 SWS, SoSe 2025)	3 ECTS 3 ECTS
3	Lecturers	Tobias Fey Dr. Maria Rita Cicconi	

4	**Module coordinator**	Tobias Fey Prof. Dr. Dominique Ligny
5	**Contents**	|Processing of Ceramics| • º Halbleiter und Leiter (Defektstrukturen, Dotierung) º Anwendungsbeispiele º advanced experiments on the production and characterization of ceramics |Functional and Optical Properties of Glass and Ceramics | Semiconductors and conductors (defect structures, doping) application examples
6	**Learning objectives and skills**	Die Studierenden • º haben ein vertieftes Verständnis folgender Eigenschaften von Glas und Keramik: optische, elektrische, thermische und mechanische Eigenschaften º erlernen die Prozesse zur Herstellung von Gläsern und Keramiken sowie die Methoden zur Bestimmung wichtiger Eigenschaften, Erklärung der Zusammenhänge zwischen Zusammensetzung, Gefüge, Eigenschaften º deepen the practical knowledge in the field of production of ceramic materials have a deeper understanding of the following properties of glass and ceramics: optical, electrical, thermal and mechanical properties learn the processes for the production of glasses and ceramics as well as the methods for determining important properties, explain the relationships between composition, microstructure, properties
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable derzeit mündliche Prüfung (15 Min.) currently taking an oral exam (15 min.)
11	**Grading procedure**	Variable (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 45 h

		Independent study: 105 h
14	**Module duration**	2 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

Computational Optics

1	**Module name** 43221	**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 of optical waves • Finite-difference method for solving Maxwell's equations • Beam propagation methods • Rate equations for photons • Application in the simulation of lasers and thin-film solar cells
6	**Learning objectives and skills**	Students should be able to • Apply various simulations methods in optics • Analyse the stability of simulation methods • Develop software for the simulation of optical waves
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**	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**	[1] A. Ta ove and S. Hagness. Computational Electrodynamics: The Finite- Difference Time-Domain Method. Artech House, Boston, London, 2000. [2] Siegman. Lasers. University Science Books Sausalito, California. [3] R. Kr#oger and R.Unbehauen. Technische Elektrodynamik. Teubner Stuttgart, 1987. [4] Christopher C.Davis. Lasers and Electro-Optics (Fundamentals and En- gineering) Cambridge University Press.

			[5] Coldren and Corzine Diode Lasers and Photonic Integrated Circuits Wiley [6] Amnon Yariv. Introduction to Optical Electronics. [7] Amnon Yariv. Optical Waves in Crystals. [8] Koechner. Solid-State Laser Engineering. [9] Hecht. Optik. [10] Braess. Finite Elemente Springer. [11] Ihlenburg. Finite Element Analysis of Acoustic Scattering. Springer. [12] Jianming Jin. The Finite Element Method in Electromagnetics. John Wiley & Sons. [13] Altmann, P aum, Seider. 3D Finite Element Computation of Laser Cavity Eigenmodes. Applied Optics-LPE . vol. 43, issue 9, page 1892, 2004. [14] F. Ihlenburg. Finite Element Analysis of Acoustic Scattering, volume 132 of Springer Series Applied Mathematical Sciences. Springer, New York, Paris, London, 1998.

1	**Module name** 43386	**Computational Photography and Capture** Computational photography and capture	**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	Dr.-Ing. Vanessa Klein Muhammad Sohail Prof. Dr. Tim Weyrich	

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 module 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**	The students ... • ... know the basic vocabulary of computational photography • ... understand principles of light transport in natural scenes • ... understand principles of digital image formation • ... understand how computational-photography algorithms can exploit knowledge of these principles to transcend the capabilities of traditional photograph • ... apply image-processing algorithms to analyse and transform images • ... apply acquisition algorithms to capture appearances and 3D scene • ... develop 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) Die Prüfung richtet sich nach dem didaktischen Charakter des Moduls und umfasst entweder eine mündliche Prüfung von 30 min oder eine Klausur von 60 min Dauer. Die Entscheidung für eine Prüfungsform wird

		in Semestern, in denen die Lehrveranstaltungen stattfinden, spätestens zwei Wochen nach Vorlesungsbeginn in der Lehrveranstaltung bekannt gegeben. In Semestern, in denen keine Lehrveranstaltungen stattfinden, wird die Prüfungsform spätestens zwei Monate vor der Wiederholungsprüfung durch E-Mail an die angemeldeten Prüflinge bekannt gegeben. The concrete form of examination (30 min. oral exam or 60 min. written exam) is defined at the beginning of the semester depending on the didactic character of the class. In semestern when the lecture is held, it will be announced in the lecture non later than 2 weeks after the lecture start. In semestern when the lecture is not held, it will be announced 2 months prior to the repetition exam via email to registered participants.
11	**Grading procedure**	Variable (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**	

1	**Module name** 44120	**Pattern Analysis** Pattern analysis	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Pattern Analysis (4 SWS)	5 ECTS
3	Lecturers	Christian Riess	

4	**Module coordinator**	Christian Riess
5	**Contents**	This lecture is the sequel to the lecture "Pattern Recognition". As such, it covers topics from the chapters 8-14 from the book "Pattern Recognition and Machine Learning" by Christopher Bishop. These topics include various aspects of Bayesian modeling, including (but not limited to) probabilistic graphical models, mixture modeling, variational inference, sampling methods, manifold learning, Markov random fields, hidden Markov models, tree-based methods and ensembling.
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
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 (60 minutes) Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten. / The form of examination is a written exam with multiple choice with a duration of 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	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	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**	german or english english
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** 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	Dr.-Ing. Vanessa Klein Muhammad Sohail Prof. Dr. Tim Weyrich Prof. Dr. Bernhard Egger	

4	**Module coordinator**	Prof. Dr. Tim Weyrich
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**	Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (90 minutes) Dieses Modul wird mit einer Klausur (90 Minuten) geprüft. The form of examination is a written exam of 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** 67156	**Quantum Computing** Quantum computing	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Computing (2 SWS) Übung: Quantum Computing - Übung	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 • understand the origin of the computation potential of quantum computers • understand key quantum algorithms, such as Deutsch algorithm, quantum phase estimation and Shor's algorithm • understand the working principle of quantum error correction and key error correcting codes • code quantum algorithms in a modern quantum programming language • are able to apply the learned methodology to example problems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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**	Irregular
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**	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** 93173	**Computational Visual Perception** Computational visual perception	**7,5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Bernhard Egger Prof. Dr. Andreas Kist Prof. Dr.-Ing. Andreas Maier
5	**Contents**	How do humans perceive the visual world? How can we build computational models to mimic this human perception? And how can we validate those computational models? This course is designed as an introduction to enable you to build computational models for human visual perception. It will therefore provide an introduction into the human visual system building on the course on cognitive neuroscience for AI developers. You will learn how the human eye and brain process visual input and what we currently know about the ventral visual stream. We will look at computational models for all different levels of visual processing and discuss how well they measure behavioral data. This lecture is designed to be at the intersection of Computer Science (Computer Vision and Graphics) and Cognitive Neuroscience. After an initial introductory phase, you will in small teams (1-3 students) perform a project to build prototypes for computational models for visual processing, reproduce recent scientific results or experiment with existing models. In addition to the project phase we will read and discuss recent research papers studying potential computational models and investigate how we can evaluate computational models. Please sign up via studon
6	**Learning objectives and skills**	By the end of this course, students will be able to • Describe the basic processing steps of visual input in the human brain • Build a computational model for a known processing step • Read recent papers in the discipline and design a follow-up experiment • Choose/design and conduct a small research project • Choose adequate methods to evaluate a computational model • Work in and manage projects
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 4
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Tutorial achievement Written (60 minutes) There are 3 exercises, and participants must pass 2 of them. There is no separate grade for the exercises (only pass/fail).

11	**Grading procedure**	Tutorial achievement (pass/fail) Written (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h Independent study: 135 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 67016	**Photonic Machine Learning** Implementations of Quantum Error Correction	**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. Birgit Stiller
5	**Contents**	<u>**What is photonic machine learning and why does it exist?**</u> *Artificial neural networks* (ANNs) have emerged as a powerful tool, which are for example used to accelerate medical research and for language processing. The freedom and power gained through the complexity of ANNs comes with the cost of a computational intense model training, eventually leading to a high energy consumption. For instance, the training of the recently published and much discussed large-language model ChatGPT 4 cost more than 100 million dollars. A reason for those high cost of ANNs is the underlying computing hardware, which is based on a von Neumann architecture, which simplifies means the separation of memory and processing units. As consequence, researchers study more specific beyond von Neumann architectures specifically designed for machine learning and deep learning applications. One possible solution to overcome the current limitations, could be the transfer of electronical ANNs into the optical domain. The resulting *optical neural networks* (ONNs) have attracted great interest over the last decades due to their promises of high processing speed, broad bandwidth, and low dissipative losses. Especially the collapse of many computational steps into a single process, which is natural in most ONNs, strongly increases the computational efficiency. Thus, ONNs are considered to path the way towards energy efficient and highly parallel optical circuits, which will have a significant impact on the performance and capabilities of future artificial neural networks. Multiple publications have demonstrated the capabilities of ONNs already. <u>**What are we going to discuss?**</u> The aim of the seminar is to give the audience an overview of the photonic machine learning community. How detailed this overview is, of course, depends on the number of participants. In general, we would select the topics from the following categories: • Optical fully-connected feedforward neural networks • Optical reservoir computing and other extreme learning machines • Photonic neural networks for image classification • Photonic neural networks for language classification, e.g., optical transformers • Limits of photonic neural networks and approaches beyond photonics

6	**Learning objectives and skills**	**<u>Goal of the seminar</u>** • Overview of cutting-edge science | Participants are exposed to recent developments in photonic machine learning and gain an overview about it. • Presenting science | Participants are supported in developing a comprehensive and engaging narrative for presentations • Extracting information | Participants will learn to extract relevant information from research papers in preparation for their literature review for their master's thesis. • Organization of information | Participants learn to collect, organize and process information from scientific papers
7	**Prerequisites**	**<u>I don’t have background in machine learning, can I still participate?</u>** We do not expect a deep background in machine learning, however, expect a curious and proactive mentality to explore and learn new and unknown concepts.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Computational Optics Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Seminar achievement (45 minutes) This seminar explores recent developments in the field of *photonic machine learning*. Participants will present their topic in a seminar talk (30min) and have a discussion (15-30min) with the audience.
11	**Grading procedure**	Seminar achievement (100%)
12	**Module frequency**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Suitable topics will be provided by the supervisors.

1	**Module name** 67212	**Methods in theoretical quantum optics**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Methods in theoretical quantum optics (4 SWS)	5 ECTS
3	Lecturers	PD Dr. Andrea Aiello	

4	**Module coordinator**	PD Dr. Andrea Aiello
5	**Contents**	The goal of this course is to furnish the students the main conceptual and calculation tools, used in typical theoretical research projects in quantum optics. These tools include operators algebra at increasing level of complexity for the study of single- and multimode states of the electromagnetic field, elementary concepts of group theory, some probability and random variable theory, and functional methods in quantum optics (mainly functional derivatives and path integration).
6	**Learning objectives and skills**	At the end of the lectures the students will be able to read and understand theoretical research papers in quantum optics, and to apply the learned concepts to their own future research.
7	**Prerequisites**	The course is targeted to MSc students since the main topic is "advanced quantum optics". It is assumed that students were already exposed to the quantization of the electromagnetic field. However, only knowledge of the elementary quantization of the transverse field in the Coulomb gauge is required to understand the lectures.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Computational Optics 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
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**	• The quantum theory of light, by Rodney Loudon, Oxford University Press • Optical Coherence and Quantum Optics, by Leonard Mandel and Emil Wolf, Cambridge University Press

		• Fundamental of Quantum Optics, by John R. Klauder and E. C. G. Sudarshan, Dover Publications, Inc. • Methods in theoretical Quantum Optics, by Stephen M. Barnett, and Paul M. Radmore, Oxford Science Publications In addition, lecture notes will be provided.

Physics of Light

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**	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**	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	**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 • "Laser dynamics by Thomas Erneux and Pierre Glorieux, Cambridge University Press 2010

1	**Module name** 42155	**Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics**	**10 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Joachim Zanthier
5	**Contents**	*Contents* • o 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
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**	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	**Workload in clock hours**	Contact hours: 105 h Independent study: 195 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	Christopher Foot: Atomic physics Saleh Teich: Fundamentals of Photonics Mark Fox: Quantum Optics: an introduction

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**	Optics in Communication Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination PL: oral examination 30 Min.
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: 30 h Independent study: 120 h
15	**Module duration**	1 semester
16	**Teaching and examination language**	english
17	**Bibliography**	-

1	**Module name** 67143	**Advanced nonlinear optics**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Maria Chekhova Dr. Hannieh Fattahi Prof. Dr. Nicolas Joly
5	**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**	The student will be able • to choose the most appropriate optical fibre (microstructured or not, solid-core or gas-filled hollow-core) for generating a supercontinuum or pair of sidebands for a dedicated experiment • to design the appropriate tapered optical fibre to obtain an efficient nonlinear process • to use nonlinear optical effects for generating non-classical light, such as photon pairs or squeezed light; • to understand how nonlinear optics works at nanoscale.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular

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**	

1	**Module name** 67156	**Quantum Computing** Quantum computing	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Computing (2 SWS) Übung: Quantum Computing - Übung	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 • understand the origin of the computation potential of quantum computers • understand key quantum algorithms, such as Deutsch algorithm, quantum phase estimation and Shor's algorithm • understand the working principle of quantum error correction and key error correcting codes • code quantum algorithms in a modern quantum programming language • are able to apply the learned methodology to example problems
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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**	Irregular
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**	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** 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**	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**	Irregular
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 120 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**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. Christoph Marquardt	

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**	The students will be able • to derive the equations yielding the conversion efficiency of a nonlinear process based on either chi-2 or chi-3 material • to properly choose the right type of material for the best conversion efficiency in case of second-harmonic, sum-frequency or different frequency • to calculate the phase-matching condition that yields efficient nonlinear effect either using a crystal or an optical fibre • to design a parametric amplifier, phase-sensitive or phase insensitive; • to use nonlinear optical effects for the frequency conversion.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	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**	**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. 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**	semester: 1
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**	Irregular
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** 67092	**Introduction to Quantum Communication** Introduction to quantum communication	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Introduction to 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**	**Inhalt:** • Introduction to quantum communication: Motivation and practical impact Introduction and refresh of fundamentals of quantum mechanics Basics of information theory Definition of a quantum state in quantum optics Fundamental principle of quantum key distribution Fundamental principle of quantum communication (classical and quantum capacity) Detailed steps of quantum key distribution Security proofs (epsilon security) Modulation of quantum states Detection of quantum states Electronics for coherent communication Error correction codes Practical implementations Combination with classical cryptography Fiber-based systems Free space and satellite-based systems Quantum repeaters
6	**Learning objectives and skills**	The students are learning the foundations of modern quantum communication and study concrete examples of quantum communication protocols. They should be able to quantitatively solve fundamental problems and understand scientific articles in the field. The lecture will introduce the foundations and aspects of implementation of quantum key distribution protocols. It will introduce experimental requirements and real-world applications and highlight interfaces to classical communication and cryptography.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Optics in Communication 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) 1)
11	**Grading procedure**	Written examination (100%)

12	**Module frequency**	Irregular
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**	

1	**Module name** 48311	**Modern Optics 1: Advanced Optics** Modern optics 1: Advanced optics	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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**	The students will get exposed to more advanced optical topics ranging from thin periodic layers, optical cavities and waveguides to optical fibers, plasmonics, metamaterials, angular momentum of light and modern microscopy techniques. They will also apply newly introduced methods to specific examples.
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Optical Material and Systems Master of Science Advanced Optical Technologies 20222 Optical Metrology Master of Science Advanced Optical Technologies 20222 Physics of Light Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes) PL: Oral examination 30 min.
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**	Christopher Foot: Atomic physics

			Saleh Teich: Fundamentals of Photonics Mark Fox: Quantum Optics: an introduction

1	**Module name** 67212	**Methods in theoretical quantum optics**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Methods in theoretical quantum optics (4 SWS)	5 ECTS
3	Lecturers	PD Dr. Andrea Aiello	

4	**Module coordinator**	PD Dr. Andrea Aiello
5	**Contents**	The goal of this course is to furnish the students the main conceptual and calculation tools, used in typical theoretical research projects in quantum optics. These tools include operators algebra at increasing level of complexity for the study of single- and multimode states of the electromagnetic field, elementary concepts of group theory, some probability and random variable theory, and functional methods in quantum optics (mainly functional derivatives and path integration).
6	**Learning objectives and skills**	At the end of the lectures the students will be able to read and understand theoretical research papers in quantum optics, and to apply the learned concepts to their own future research.
7	**Prerequisites**	The course is targeted to MSc students since the main topic is "advanced quantum optics". It is assumed that students were already exposed to the quantization of the electromagnetic field. However, only knowledge of the elementary quantization of the transverse field in the Coulomb gauge is required to understand the lectures.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Computational Optics 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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	no Module frequency information available!
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**	• The quantum theory of light, by Rodney Loudon, Oxford University Press • Optical Coherence and Quantum Optics, by Leonard Mandel and Emil Wolf, Cambridge University Press

		• Fundamental of Quantum Optics, by John R. Klauder and E. C. G. Sudarshan, Dover Publications, Inc. • Methods in theoretical Quantum Optics, by Stephen M. Barnett, and Paul M. Radmore, Oxford Science Publications In addition, lecture notes will be provided.

1	**Module name** 67211	**Quantum Information Processing: Implementations**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Quantum Information Processing: Implementations	-
3	Lecturers	Prof. Dr. Christopher Eichler	

4	**Module coordinator**	Prof. Dr. Christopher Eichler
5	**Contents**	Keywords: Introduction to experimental systems for quantum information processing (QIP). Quantum bits. Quantum Computing. Coherent Control. Measurement. Decoherence. Microscopic and macroscopic quantum systems. Trapped Ions, Rydberg Atoms, Photons, Quantum Dots, NV centers, Superconducting Circuits. During the past 20 years quantum physics has entered the domain of information technology in increasingly profound ways. Rapid progress in the physical sciences and in engineering and technology has allowed us to build information processing devices, which utilize the laws of quantum physics. In these processors information is stored in quantum states rather than classical states. As such the the superposition principle and entanglement can be exploited as new resources for processing, storing and protecting information. Information processors using quantum physics are expected to become potentially more powerful than their classical counterparts. Developments in this research field are driven by academic labs, startups and major industrial cooporations. The goal of this course is to provide a thorough introduction to physical implementations pursued in current research for realizing quantum information processors. The field of quantum information science is one of the fastest growing and most active domains of research in modern physics. Introduction to experimental systems for quantum information processing (QIP). - Quantum bits - Coherent Control - Measurement - Decoherence - DiVincenzo criteria QIP with - Ions - Superconducting Circuits - Photons - NMR - Rydberg atoms - NV-centers - Quantum dots

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**	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 (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	

Related Fields

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: IntroML-Ex (2 SWS) Übung: IntroML-Tut (2 SWS)	5 ECTS 1,25 ECTS -
3	Lecturers	Dr.-Ing. Vincent Christlein Linda-Sophie Schneider	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Das Modul 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. Das Modul 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. Das Modul schließt mit einer Einführung in die maschinelle Klassifikation. In diesem Kontext wird der Bayes- und der Gauss-Klassifikator besprochen. The module aims to familiarize students with the basic structure of a pattern recognition system. The individual steps from the acquisition of data to the classification of patterns are explained. The module starts with a short introduction, which also introduces the used nomenclature. Analog-to-digital conversion is introduced, with emphasis on its impact on further signal analysis.Common methods of preprocessing are then described. An essential component of a pattern recognition system is feature extraction. Various approaches to feature computation/ transformation are demonstrated, including moments, principal component analysis, and linear discriminant analysis.In addition, ways to learn feature representations directly from the data are presented. The module concludes with an introduction to machine classification. In this context, the Bayes and Gauss classifiers are discussed. T
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 The students • explain the stages of a general pattern recognition system • understand sampling, the sampling theorem, and quantization • understand and implement histogram equalization and expansion • compare different thresholding methods • understand linear, shift invariant filters and convolution • apply various low-pass, high-pass, and nonlinear filters • apply different normalization methods • understand the curse of dimensionality • explain different heuristic feature calculation methods, e.g. projection on an orthogonal base space, geometric moments, features based on filtering • understand analytical feature computation methods, e.g. principal component analysis, linear discriminant analysis • understand the basis of representation learning • explain the basics of statistical classification (Bayes classifier) • use the programming language Python to apply the presented pattern recognition methods • learn practical applications and apply the presented algorithms to concrete problems
7	**Prerequisites**	Ein Mustererkennungssystem besteht aus den folgenden Stufen: Aufnahme von Sensordaten, Vorverarbeitung, Merkmalsextraktion und maschinelle Klassifikation. Dieses Modul beschäftigt sich in erster Linie mit den ersten drei Stufen und schafft damit die Grundlage für weiterführende Module (Pattern Recognition und Pattern Analysis).

		A pattern recognition system consists of the following stages: Sensor Data Acquisition, Preprocessing, Feature Extraction, and Machine Classification. This module primarily deals with the first three stages and thus creates the basis for more advanced modules (Pattern Recognition and Pattern Analysis).
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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/lecture slides • 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** 67172	**Methods of Data Analysis I** Methods of data analysis I	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Anna Nelles Prof. Dr. Christopher van Eldik
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**	Students • understand the basic concepts of probability and statistics • gain an understanding of the relevance of statistics for experimental data • learn how to statistically interpret data • understand how to chose the relevant statistical method
7	**Prerequisites**	To successfully follow this lecture basic knowledge of Python is advantageous. Alternatively, participants should be willing to learn how to program alongside this class. It is recommended to first complete "Datenverarbeitung in der Physik (DV)".
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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**	Irregular
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 • Luca Lista: "Statistical Methods for Data Analysis in Particle Physics", ISBN: 978-3-319-62839-4

1	**Module name** 95067	**Machine Learning for Engineers I - Introduction to Methods and Tools** Machine learning for engineers I - Introduction to methods and tools	**5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning for Engineers I: Introduction to Methods and Tools (4 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Björn Eskofier Thomas Altstidl Prof. Dr. Nico Hanenkamp Prof. Dr.-Ing. Jörg Franke	

4	**Module coordinator**	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**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination Electronic exam (online), 90min
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** 95068	**Machine Learning for Engineers II: Advanced Methods** Machine learning for engineers II: Advanced methods	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning for Engineers II: Advanced Methods (2 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) This is a vhb course (online).
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**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (60 minutes) Electronic exam (online), 60min
11	**Grading procedure**	Written examination (100%) Electronic exam (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** 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)	5 ECTS -
3	Lecturers	Prof. Dr. Florian Marquardt Sangkha Borah	

4	**Module coordinator**	Prof. Dr. Florian Marquardt
5	**Contents**	This is a course introducing modern techniques of machine learning, especially deep neural networks, to an audience of physicists. Neural networks can be trained to perform diverse challenging tasks, including image recognition and natural language processing, just by training them on many examples. Neural networks have recently achieved spectacular successes, with their performance often surpassing humans. They are now also being considered more and more for applications in physics, ranging from predictions of material properties to analyzing phase transitions. We will cover the basics of neural networks, convolutional networks, autoencoders, restricted Boltzmann machines, and recurrent neural networks, as well as the recently emerging applications in physics. Prerequisites: almost none, except for matrix multiplication and the chain rule.
6	**Learning objectives and skills**	• explain the relevant topics of the lecture • apply methods to specific examples
7	**Prerequisites**	None
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	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**	Irregular
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**	https://pad.gwdg.de/s/Machine_Learning_For_Physicists_2023

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

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
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**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (90 minutes) Written exam, 90 min.
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** 66941	**Advanced experimental physics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced experimental physics: Solid state physics (4 SWS)	10 ECTS
		Vorlesung: Advanced experimental physics: Particle and astroparticle physics (4 SWS)	10 ECTS
		Übung: Advanced experimental physics: Solid state physics (Exercise class) (3 SWS)	-
		Übung: Advanced experimental physics: Particle and astroparticle physics (Excercise class) (3 SWS)	-
3	Lecturers	Prof. Dr. Daniele Fausti Prof. Dr. Christopher van Eldik Dr. Angela Montanaro Dr. Giacomo Jarc	

4	**Module coordinator**	Prof. Dr. Stefan Funk Prof. Dr. Vojislav Krstic 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: Particle 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**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written or oral • Examination for Advanced Experimental Physics: Lasers, Atomic Physics and Quantum Optics (EV-A): written examination (120 min) • Examination for Advanced Experimental Physics: Particle and Astroparticle Physics (EV-B): oral examination (30 min) • Examination for Advanced Experimental Physics: Solid State Physics (EV-C): oral examination (30 min)
11	**Grading procedure**	Written or oral (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 90 h

		Independent study: 210 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

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: Solid state physics (Exercise class) (3 SWS)	10 ECTS -
3	Lecturers	PD Dr. Michael Schmiedeberg	

4	**Module coordinator**	Prof. Dr. Kristina Giesel Prof. Dr. Hanno Sahlmann PD Dr. Michael Schmiedeberg 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**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Written examination (120 minutes) **Course Advanced Solid State Physics (TV-B):** There will be weekly problem sheets for homework. Each week, the solution of the first problem on the respective problem sheet can be submitted voluntarily in writing for correction. Students who receive at least 50% of the points for their solutions will receive a grade bonus of 0.3 or 0.4 on their exam grade. A second grade bonus of 0.3 or 0.4 can be achieved independently from the first bonus by presenting solutions for at least three problems from different problem sheets during the exercise groups.
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Every semester
13	**Workload in clock hours**	Contact hours: 105 h Independent study: 195 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 67021	**Theoretical physics: Solid state physics**	**10 ECTS**
2	Courses / lectures	Vorlesung: Advanced theoretical physics: Solid state physics (4 SWS) Übung: Advanced theoretical physics: Solid state physics (Exercise class) (3 SWS)	10 ECTS -
3	Lecturers	PD Dr. Michael Schmiedeberg	

4	**Module coordinator**	Prof. Dr. Ana-Suncana Smith
5	**Contents**	*Contents:* *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**	*Learning goals and competences:* 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**	no Integration in curriculum available!
9	**Module compatibility**	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	**Workload in clock hours**	Contact hours: 105 h

		Independent study: 195 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	*Literature:* • U. Rössler, Solid State Theory: An Introduction • G. Czycholl, Theoretische Festkörperphysik • N.W. Ashcroft, N.D. Mermin, Solid State Physics • L. Kantorovich, Quantum Theory of the Solid State: An Introduction • C. Kittel, Quantum Theory of Solids • J.M. Ziman, Principles of the theory of solids

1	**Module name** 43230	**Functional Analysis for Engineers** Functional analysis for engineers	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Christoph Pflaum
5	**Contents**	• vector spaces, norms, principal axis theorem • Banach spaces, Hilbert spaces • Sobolev spaces • theory of elliptic differential equations • Fourier transformation • distributions
6	**Learning objectives and skills**	Students learn advanced methods in linear algebra and basic concepts of functional analysis. Furthermore, students learn applications in solving partial differential equations. The course teaches abstract mathematical structures.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Tutorial achievement Written examination (60 minutes)
11	**Grading procedure**	Tutorial achievement (pass/fail) 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**	• Lehrbuch: Dobrowolski, Angewandte Funktionalanalysis, Springer 2006.

1	**Module name** 47677	**Data Science Survival Skills** Data science survival skills	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	Prof. Dr. Andreas Kist
5	**Contents**	Data Scientists need a comprehensive toolbox for their work. This consists for example of data acquisition, data cleaning, data processing and data visualization. In this course, we highlight good practices and approaches, and provide intensive hands-on experience. In particular, this course covers: Data handling and storage Lossy and lossless data compression Data acquisition and API usage Data visualization in scientific figures and movies Data analysis platforms Multithreading and multiprocessing Code vectorization and just-in-time compilation Code profiling Prototyping Graphical User Interfaces Workflow optimization techniques
6	**Learning objectives and skills**	Students will be able to create own code for working with data can carry out research projects in data science can apply code optimization strategies can design own graphical user interfaces for convenient interaction with data can produce high-quality data visualization as needed for scientific publications
7	**Prerequisites**	It is recommended to have prior knowledge of the programming language Python (e.g. through GSProg or SciProgPy) and first exposure to data.
8	**Integration in curriculum**	semester: 1
9	**Module compatibility**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Variable (60 minutes) Compulsory: Written Exam, 60 min Optional: Homework (12-14 units)
11	**Grading procedure**	Variable (100%) The grade consists of the exam grade to 100%. We grant bonus points according to passed homework units (up to a grade advantage of 0.7, if the exam was passed with at least grade 4.0).
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**	Edward Tufte: The Visual Display of Quantitative Information Cole Nussbaum Knaflic: Storytelling with data Wes McKinney: Python for Data Analysis: Data Wrangling with Pandas, NumPy, and IPython Gabriele Lanaro: Python High Performance Micha Gorelick, Ian Ozsvald: High Performance Python Alan D Moore: Mastering GUI Programming with Python

1	**Module name** 44171	**Advanced Programming Techniques**	**5 ECTS**
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	**Module coordinator**	apl. Prof. Dr. Harald Köstler
5	**Contents**	The content of the lecture will consist of various topics of advanced C++ programming, aimed at teaching the proper and efficient usage of C++ for professional software development. These are basic language concepts, the C++11/C++14/C++17 standards, object oriented programming in C++, static and dynamic polymorphism, template metaprogramming, and C++ idioms and design patterns.
6	**Learning objectives and skills**	Wissen: Lernende können die grundlegenden Sprachkonstrukte in den verschiedenen C++ Standards wiedergeben. Students know the basic language constructs from different C++ standards. Verstehen: Lernende verstehen das C++ Objektmodell und können es mit anderen Programmiersprachen vergleichen. Students understand the C++ object model and are able to compare it to other programming languages. Anwenden: Lernenden können Standardalgorithmen in einer objektorientierten Programmiersprache implementieren. Students can implement standard algorithms in an object oriented programming language. Analysieren: Lernende können gängige Design Patterns klassifizieren und deren Anwendbarkeit für bestimmte Probleme diskutieren. Students are able to classify common design patterns and to discuss their usability for certain problems. Evaluieren (Beurteilen): Lernende können entscheiden, welches Software Design passend für eine bestimmte Aufgabe ist. Sie können auch den Implementierungsaufwand dafür abschätzen. Students can decide, which software design fits for a certain task. They are also able to estimate the programming effort for it. Erschaffen: Lernende entwickeln selbständig in einer Gruppe ein größeres Softwarepaket im Bereich Simulation und Optimierung. Students develop together in a group a larger software project in the area of simulation and optimization on their own Fachkompetenz Anwenden

		Students are able to implement standard algorithms in an object oriented language.
7	**Prerequisites**	*Die Übung "Advanced Programming Techniques" im Umfang von 2,5 ECTS kann in den Wahlvertiefungsbereich B8 eingebracht werden.*
8	**Integration in curriculum**	semester: 5
9	**Module compatibility**	Related Fields Master of Science Advanced Optical Technologies 20222 **Zu diesem Modul gehört eine verplfichtende Übung im Wert von 2,5 ECTS, die in den Wahlvertiefungsbereich B8 eingebracht werden kann.**
10	**Method of examination**	Written examination (60 minutes)
11	**Grading procedure**	Written examination (100%)
12	**Module frequency**	Only in winter semester
13	**Workload in clock hours**	Contact hours: 40 h Independent study: 110 h
14	**Module duration**	1 semester
15	**Teaching and examination language**	english
16	**Bibliography**	

1	**Module name** 67141	**Elements of Artificial Intelligence for Scientific Discovery**	**5 ECTS**
2	Courses / lectures	Hauptseminar: Elements of Artificial Intelligence for Scientific Discovery (2 SWS)	5 ECTS
3	Lecturers		

4	**Module coordinator**	Prof. Dr. Florian Marquardt
5	**Contents**	This lecture course will give an overview and sketch the basics of advanced modern methods of artificial intelligence and machine learning. It will describe how they are used in artificial scientific discovery, in physics and other fields. Artificial scientific discovery aims to automatize all aspects of the scientific process.We will discuss (and also implement, in the tutorials): • how to extract the essence of data (representation learning) • how to choose the best experiments to do (active learning / experimental design) • how to come up with scientific hypotheses automatically and how to rule them out • how to discover optimal strategies (reinforcement learning) • how to learn the statistics of observations and reproduce them (generative probabilistic modeling)The modern tools discussed will include transformers, diffusion models, and graph neural networks. In addition, we provide the basics of information science and statistics needed to understand these approaches.

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**	Related Fields 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	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	**Module duration**	?? semester (no information for Module duration available)
15	**Teaching and examination language**	german
16	**Bibliography**	

1	**Module name** 67209	**Open Quantum Systems**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Open Quantum Systems	5 ECTS
3	Lecturers	Petr Zapletal	

4	**Module coordinator**	Petr Zapletal
5	**Contents**	All quantum systems must be regarded as open systems since they can never be perfectly isolated from their surroundings. In particular, the control of quantum experiments always involves external interventions such as the illumination by laser light. The interaction of quantum systems with their environment inherently leads to irreversible effects of dissipation and decoherence, which play a key role in state-of-the-art quantum experiments. On the other hand, maintaining quantum coherence for a long time is crucial for the development of quantum technologies, such as quantum computing. In this course, we will first derive the equation of motion – the quantum master equation – from the microscopic theory of open quantum systems. Then, we will discuss universal dynamical maps and the quantum jump approach. Finally, we will employ this formalism to discuss the loss of quantum superpositions and entanglement due to the coupling of quantum systems to their environment. During tutorials, you will use analytical methods to describe the evolution, steady states, and symmetries of open quantum systems. Additionally, you will learn how to numerically solve the quantum master equation using the Python library "QuTiP".
6	**Learning objectives and skills**	You will learn how quantum systems interact with their environment and how this interaction gives rise to phenomena like decoherence and dissipation. Furthermore, you will acquire analytical and numerical methods required to describe these effects in quantum experiments, including quantum optical systems, and quantum devices such as noisy intermediate-scale quantum computers.
7	**Prerequisites**	Knowledge of quantum mechanics including the concepts of quantum states, density matrices, unitary evolution, Schrödinger equation, and measurements.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Related Fields Master of Science Advanced Optical Technologies 20222
10	**Method of examination**	Oral (30 minutes)
11	**Grading procedure**	Oral (100%)
12	**Module frequency**	Irregular
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**	• Open Quantum Systems: An Introduction, A. Rivas and S. F. Huelga, (2012). Preprint version of the published book available at https://arxiv.org/abs/1104.5242 • The Theory of Open Quantum Systems, H.-P. Breuer and F. Petruccione, Oxford University Press (2007). • Quantum optics, D. F. Walls and G. J. Milburn, (2nd ed.). Springer (2008). • Quantum Measurement and Control, H. M. Wiseman and G. J. Milburn, Cambridge University Press (2009).