FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

MAOT master programme in advanced optical technologies

Module Handbook

Master programme Advanced Optical Technologies (MAOT)

22.02.2017

Overview

Topic: Fundamentals

Modules:
- Topics of Optical Technologies
- Numerical Methods in Optics
- Fundamentals of Optics
- Basics of Laser

Topic: Optical Metrology

Modules:
- Modern Optics I: Advanced Optics (Main topic: Physics of Light)
- Physics of Biosensing (Main topic: Optics in Medicine)
- Light Scattering
- Dynamic Light Scattering
- Thermophysical Properties of Working Materials in Process and Energy Engineering
- Product Analysis

Topic: Optical Material Processing

Modules:
- Advanced Laser (Main topic: Optical Materials and Systems)
- Laser-Tissue-Interaction (Main topic: Optics in Medicine)
- Lasersystemtechnologie 2
- Lasersystemtechnologie 1
- Optical Litography: Technology, Physical Effects, and Modeling (Main topic: Optical Materials a Systems)
- Laser Technology
- Optical Technologies in Life Science (Main topic: Optical Metrology)

Topic: Optics in Medicine

Modules:
- Physics of Biosensing
- Photonics in Medical Engineering
- Laser-Tissue-Interaction
- Clinical Applications of Optical Technologies and Associated Fundamentals of Anatomy
- Image Processing in Optical Nanoscopy (Main topic: Computational Optics)
- Interventional Medical Image Processing (Main topic: Computational Optics)
- Diagnostical Medical Image Processing (lecture only) (Main topic: Computational Optics)

Topic: Optical Materials and Systems

Modules:
- Nanospectroscopy
- Phosphors
- Quantum and classical experiments with structured light (Main topic: Physics of Light)
- Advanced Laser
- Optical Litography: Technology, Physical Effects, and Modeling
- Solar Energy

Topic: Optics in Communication and Information Technology

Modules:
Nonlinear optics in 1D-photonic structures

Non-linear Optics (Main topic: Physics of Light)

Quantum Optics

Optical Communication Networks

Advanced Optical Communication Systems

Linear and non-linear fibre optics

Topic: Computational Optics

Modules:
Computational Optics

Image Processing in Optical Nanoscopy

Pattern Analysis

Pattern Recognition

Interventional Medical Image Processing

Diagnostical Medical Image Processing (lecture only)

Topic: Physics of Light

Modules:
Quantum and classical experiments with structured light

Nonlinear optics in 1D-photonic structures (Main topic: Optics in Communication and Informatio Technology)

Modern Optics I: Advanced Optics

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

Non-linear Optics

Advanced Laser (Main topic: Optical Materials and Systems)

Quantum Optics (Main topic: Optics in Communication and Information Technology)

Topic: Topics

Modules:
Lab courses

Module name:	**Basics of Laser**
Topic(s):	Fundamentals
Coordinator(s):	Prof. Dr. Nicolas Joly
Lecturer(s):	Prof. Dr. Nicolas Joly

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Basics of Laser

Content

The module provides basic knowledge of Laser. This will cover the following topics:
• Introduction: basic components of a laser, properties of the emitted radiation, spontaneous emission, absorption, stimulated emission, rate equation, steady states, linear stability analysis, three-level system, four-level system, population inversion,
• Gaussian optics: ray matrices, Gaussian beam, laser modes,
• Passive resonators: Fabry-P´erot cavity, stability of a resonator, ABCD law for a cavity,
• Pulsed lasers: dynamics of lasers, class-B laser and Q- switch, mode-locking
In two lab sessions the students will work on two setups:
• Intro to the Nd:YAG laser kit. Threshold of the pump diode. Msmt of the fluorecense life-time. Cavity alignment. Laser threshold. Observation of transversal modes. Spiking.
• Intro to the Erbium doped fiber laser. Threshold of the pump diode. Fabry-Perot cavity. Laser threshold. Spiking

Learning objectives

Students
• explain the relevant topics of the lecture
• apply the methods to specific examples

Literature

• O. Svelto.Principles os Lasers,. Springer, New-York, 5th edition, 2010
• F. Träager. Handbook of Lasersand Optics, Springer Science, 2007
• C.E. Webb and J.D.C. Jones: Handbook of Laser Technology and Applications, CRC, Press, IOP, 2003

Prerequsites

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Exam: 90 min oral + lab report

Module name:	**Fundamentals of Optics**						
Topic(s):	Fundamentals						
Coordinator(s):	Prof. Dr. Andreas Fröba						
Lecturer(s):	Prof. Dr. Andreas Fröba						
Duration:	1 semester	**ECTS:**	12	**SWS:**	15	**Cycle**	WS
Lecture/week:	8 h	**Exercise/week:**	4 h				
Classes:	120 h	**Self-study:**	180 h				
Language:	English						
Lecture(s):	Fundamentals of Optics						

Content

The module provides basic knowledge in the field of optics. It covers:

- 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,
- **Fourier Optics:** Fourier Transforms, Two-Dimensional Transforms, The Dirac Delta Function, The Convolution Integral, Fourier Methods in Diffraction Theory, Spectra and Correlation, Transfer Functions
- Basics of Coherence Theory

Learning objectives

Students

- are able to understand, describe and explain crucial concepts of optics
- are able to apply concepts of optics to solve technical and theoretical problems

Literature

Eugene Hecht: Optics

Prerequsites

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Exam: 120 min written, 30 min oral

Module name:	**Numerical Methods in Optics**
Topic(s):	Fundamentals
Coordinator(s):	Prof. Dr. Bernhard Schmauß
Lecturer(s):	Jaypee Quino Matthias Bär

Duration:	1 semester	**ECTS:**	2	**SWS:**	2	**Cycle**	WS
Lecture/week:	1 h	**Exercise/week:**	1 h				
Classes:	30 h	**Self-study:**	45 h				
Language:	English						

Lecture(s): Introduction into Matlab

Content

- What is Matlab
- Toolboxes
- the Matlab system
- Matlab as calculator
- numbers and formats
- variables, suppressing output
- vectors
- keeping a record
- elementary functions
- 2D Plots
- vector operations
- matrices – two dimensional arrays
- systems of linear equations
- characters
- strings and texts
- loops
- logicals
- functions
- plotting surfaces
- visualization of vector fields
- poynting vector
- radiating dipole

Learning objectives

Students
- do understand the basic concept of Matlab
- do know the basic functions of Matlab
- are able to apply Matlab for solving numerical problems in the field of optics

Literature

Lecture script

Prerequsites

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Exam: Weekly homework

Module name:	**Topics of Optical Technologies**
Topic(s):	Fundamentals
Coordinator(s):	Prof. Dr. Bernhard Schmauß
Lecturer(s):	Prof. Dr. Andreas Fröba Prof. Dr. Christoph Pflaum Prof. Dr. Bernhard Schmauß apl. Prof. Dr. Norbert Lindlein Dr. Ilya Alexeev Dr. Florian Klämpfl

Duration:	1 semester	**ECTS:**	2,5	**SWS:**	2	**Cycle**	WS
Lecture/week:	1 h	**Exercise/week:**	1 h				
Classes:	15 h	**Self-study:**	60 h				
Language:	English						

Lecture(s): Topics of Optical Technologies

Content

The module introduces in the topics which can be chosen as major topics in the second and third semester of MAOT. Each student gets a general introduction into two topics and works in group with other students on a presentation of an exemplary field of the topics. In plenary sessions the group present the topics to each other.

Learning objectives

Students

- know the scope of the topic, examples of current research and the covering of the lectures in MAOT
- are able to decide about their major topics for the second and third semester

Literature

Lecture script

Prerequsites

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Exam: Two group presentations

Module name:	**Dynamic Light Scattering**
Topic(s):	Optical Metrology
Coordinator(s):	Prof. Dr. Andreas Fröba
Lecturer(s):	Prof. Dr. Andreas Fröba

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Dynamic Light Scattering

Content

- DLS – Rayleigh scattering (Thermal diffusivity)
- DLS – Brillouin scattering (Speed of sound and sound attenuation)
- DLS – Rayleigh scattering (Mutual diffusivity)
- DLS – Particle Scattering (Dynamic Viscosity)
- DLS – Particle Scattering (Particle size and size distribution)
- DLS – Applications in biotechnology (Shape analysis of cells; analysis of hyaluronan)
- SLS – Transparent fluids with low viscosity and/or high surface tension (Viscosity and surface tension)

Learning objectives

Students
- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

Berne, B.J.; Pecora, R. Dynamic Light Scattering.
Lecture slides and references given in the lecture

Prerequsites

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Exam: 30 min oral

Module name:	**Light Scattering**
Topic(s):	Optical Metrology
Coordinator(s):	Prof. Dr. Andreas Fröba
Lecturer(s):	Prof. Dr. Andreas Fröba

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Light Scattering

Content

- Laser and Phase Doppler Anemometry (LDA/PDA) droplet velocities and sizes
- Mie Scattering visualization of liquid phase, spray cone angle & penetration
- Particle Image Velocimetry (PIV) flow field (planar)
- Laser-Induced Fluorescence (LIF) distribution of vapor phase and temperature
- Laser-Induced Exciplex Fluorescence (LIEF) vapor and liquid phase distribution
- Rayleigh and Brillouin Scattering density and temperature - thermophysical properties
- Raman Scattering liquid and gas phase concentration
- Coherent Anti-Stokes Raman Scattering (CARS) gas phase temperature
- Laser-Induced Incandescence (LII) Nano-particle size und concentration

Learning objectives

- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

Alexander Kokhanovsky: Light Scattering Review
Lecture slides and references given in the lecture

Prerequsites

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Exam: 30 min oral

Module name:	**Optical Technologies in Life Science**
Topic(s):	Optical Material Processing
Coordinator(s):	Prof. Dr. Dr. Oliver Friedrich
Lecturer(s):	Prof. Dr. Dr. Oliver Friedrich

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	90 h	**Self-study:**	60 h				
Language:	English						

Lecture(s): Optical Technologies in Life Science

Content

- 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 proces ses´
- 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
- High throughput screening, optical methods for screening cellular responses to chemical substances and medication

Learning objectives

- The main learning objective are a profound understanding of the basic concepts of optical technologies in life sciences and specific technological solutions on the one hand, and focused application of these technologies to fundamental research question in life sciences and medicine.
- In particular, advantages and limitation of individual technologies will be worked out and compared directly.
- Students will gain competence to select optical methods to answer specific research question in life science, and to plan scientific experiments under consideration of Advantages and limitations of required technologies.
- Students will study a specific topc in depth based on primary scientific literature and give a presentation about this topic in the seminar. Besides the in-depth study of the Content, this will also strengthen the ability to filter and structure relevant information from the literature, to select and prepare contents for presentation slides, and finally improve presentation skills as important soft skills for scientific work.

Literature

- Bruce Alberts, ‚*Molecular Biology of the Cell*‘, 4th Edition, New York, Garland Science Publisher
- 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

Prerequsites

Basic knowledge of optics and cell biology

Exam: 120 min written

Module name:	**Product Analysis**
Topic(s):	Optical Metrology
Coordinator(s):	Prof. Dr. Wolfgang Peukert
Lecturer(s):	Prof. Dr. Wolfgang Peukert Dr. Björn Braunschweig

Duration:	1 semester	**ECTS:**	5	**SWS:**	3	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	45 h	**Self-study:**	105 h				
Language:	English						

Lecture(s): Product Analysis

Content

The lecture 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

Learning objectives

- 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.

Literature

- 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 2008Wiley 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

Prerequisites

None

Exam: 30 min oral

Module name:	**Thermophysical Properties of Working Materials in Process and Energy Engineering**
Topic(s):	Optical Metrology
Coordinator(s):	Prof. Dr. Andreas Fröba
Lecturer(s):	Prof. Dr. Andreas Fröba

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Thermophysical Properties of Working Materials in Process and Ene

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

Learning objectives

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.
• conduct experiments independently by, e.g., determining viscosity and diffusion coefficients using Dynamic Light Scattering, evaluate the same properties by molecular modeling, and characterize tailor-made working fluids for high-temperature heat pump systems and organic Rankine Cylces by the development of equations of state.

Literature

• 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 UnivIS: 04.07.2016 10:28 115
- 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

Prerequsites

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Exam: 30 min oral

Module name:	**Laser System Technology 1 / Lasersystemtechnologie 1**
Topic(s):	Optical Material Processing
Coordinator(s):	Prof. Dr. Peter Hoffmann
Lecturer(s):	Prof. Dr. Peter Hoffmann

Duration:	1 semester	**ECTS:**	2,5	**SWS:**	2	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	45 h				
Language:	Deutsch						

Lecture(s): Laser System Technology 1

Content

The lecture is carried out in German language!

- 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

Learning objectives

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.

Literature

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Prerequsites

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Exam: 20 min oral

Module name:	**Laser System Technology 2 / Lasersystemtechnologie 2**
Topic(s):	Optical Material Processing
Coordinator(s):	Prof. Dr. Peter Hoffmann
Lecturer(s):	Prof. Dr. Peter Hoffmann

Duration:	1 semester	**ECTS:**	2,5	**SWS:**	2	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	45 h				
Language:	Deutsch						

Lecture(s): Laser System Technology 1

Content

The lecture is carried out in German language!

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

Learning objectives

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.

Literature

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Prerequsites

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Exam: 20 min oral

Module name:	**Laser Technology**
Topic(s):	Optical Material Processing
Coordinator(s):	Dr. Ilya Alexeev
Lecturer(s):	Dr. Ilya Alexeev

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Laser Technology

Content

- 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

Learning objectives

The student:
- would know the fundamental principles involved in the development of lasers.
- will understand the design and functionality of various types of lasers, and be able to comprehend laser specifications.
- will be able to design and analyse a free space laser beam propagation setup.
- will gain knowledge about basic optical components used in laser setups such lenses, mirrors, polarizers, etc.
- would be able to understand the basic interaction phenomena during laser-matter interaction processes.
- would be able to determine the advantages and disadvantages of using laser process for industrial applications.
- will know and be able to apply the safety principles while handling laser setups.
- will be familiar with several most common industrial application of laser for material processing such
- as cutting, welding, material ablation, additive manufacturing.
- will be familiar with metrological applications of lasers.
- will become familiar with and be able to use international (English) professional terminology.

Literature

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Prerequsites

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Exam: 120 min written

Module name:	**Clinical Applications of Optical Technologies and Associated Fundamentals of Anatomy**
Topic(s):	Optics in Medicine
Coordinator(s):	Prof. Dr. Michael Eichhorn
Lecturer(s):	Prof. Dr. Michael Eichhorn

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Clinical Applications of Optical Technologies and Associated Funda

Content

- Biological Systems
- Trunk System
- Nervous System
- Respiration
- Circulation
- Heart
- Digestion
- Neuroscience
- Functional cardiology
- Advanced endoscopy
- Advanced neuroimaging

Learning objectives

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

Literature

Gerard J. Tortora, Bryan Derrickson: Principles of Anatomy and Physiology:

Prerequsites

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Exam: 90 min written

Module name:	**Laser-Tissue-Interaction**						
Topic(s):	Optical Material Processing Optics in Medicine						
Coordinator(s):	Prof. Dr. Michael Schmidt						
Lecturer(s):	Dr. Florian Klämpfl						
Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						
Lecture(s):	Laser-Tissue-Interaction						

Content

- 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

Learning objectives

- The students can explain
- the basic properties of light using waveoptics
- scattering mechanisms of light
- the mechanisms of laser/tissue interaction
- different methods for the modelling of light propagation in tissue
- explain the RTE and apply MC for simulations of photon transport
- explain and apply the basic procedures to determine the optical properties of tissue
- explain the use and production of optical phantoms
- selected diagnostic and therapeutic applications of light and lasers

Literature

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Prerequsites

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Exam: 90 min written

Module name:	**Photonics in Medical Engineering**
Topic(s):	Optics in Medicine
Coordinator(s):	Prof. Dr. Michael Schmidt
Lecturer(s):	Dr. Florian Klämpfl

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Photonics in Medical Engineering

Content

- 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

Learning objectives

- 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

Literature

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Prerequsites

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Exam: 90 min written

Module name:	**Physics of Biosensing**
Topic(s):	Optical Metrology Optics in Medicine
Coordinator(s):	PD Dr. Frank Vollmer
Lecturer(s):	PD Dr. Frank Vollmer

Duration:	1 semester	**ECTS:**	5	**SWS:**	3	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	1 h				
Classes:	45 h	**Self-study:**	105 h				
Language:	English						

Lecture(s): Physics of Biosensing

Content

- Fundamentals of Biophotonics and Biosensing
- Physical properties of biosensors, with emphasis on optical,electrical and mechanical microsystems
- Optical, mechanical resonators
- Light matter interactions (molecular electromagnetism, multipole moments, dielectric and optical properties of molecules, absorption, fluorescence, polarizability)
- Micro structures in biosensing, signal generation, transduction, amplification, interpretation, frequency domain, time domain (microresonators, QCM, SPR, grating couplers, interferometers, nanoparticles)
- Instrumentation biosensors, sensor componentsbiosensors in analytics and clinical diagnostics (molecular interactions, molecular recognition, structurefunction in biomolecules, specific detection, diffusion, biochemical networks)
- Plasmonics
- Single molecule detection and single molecule analysis/properties
- Biology for engineering and physics

Learning objectives

The students
- Know relevant basics of biosensing
- Understand the relevant basics of optics, mechanics and electronics
- Know important material parameter, various material classes and biosensing systems
- Understand the use of biomolecules in biosensing
- Know detection mechanism of biomolecules in biosensing
- Can develop optical, mechanical and electrical sensors
- Explain the coupling of biological systems with biosensors
- Explain the use of optical material
- Understand the molecular foundation of biosensing processes
- Know the use of micro-structure in biosensing and medical diagnostic

Literature

- Hinchcliffe & Munn, Molecular Electromagnetism
- Prasad, Biophotonics
- Prasad, Nanophotonics
- J. D. Jackson, Klassische Elektrodynamik, deGruyter (2006)
- Y Yariv, Optical Electronics in Modern Communications, Oxford University Press (1997)

Prerequsites

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Exam: 30 min oral

Module name:	**Advanced Laser**						
Topic(s):	Optical Material Processing Optical Materials and Systems Physics of Light						
Coordinator(s):	Prof. Dr. Nicolas Joly						
Lecturer(s):	Prof. Dr. Nicolas Joly						
Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						
Lecture(s):	Advanced Laser						

Content

- Z-cavity
- Dispersion management for ultra-short pulse generation
- Various technique of characterisation of ultra-short pulses
- Polarisation effects and Jones' formalism
- Semi-classical model for a laser (Maxwell-Bloch equations)

The rest of the lecture will consist of seminar presented by the students on the topics of their choice. These topics should cover a particular aspect (fundamental, theoretical, applied) of a laser system or an application of laser (e.g. optical tweezer, high-precision metrology, high-resolution spectroscopy… etc).

Learning objectives

Students
- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Nanospectroscopy**
Topic(s):	Optical Materials and Systems
Coordinator(s):	Prof. Dr. Christoph J. Brabec
Lecturer(s):	Wolfgang Heiß

Duration:	1 semester	**ECTS:**	3	**SWS:**		**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	45 h				
Language:	English						

Lecture(s):

Content

- Basics of the development of phosphors and storage phosphors (energy transmission, doping, point defects in crystal structures)
- Methods of spectroscopic analysis of ligands around luminescence ions
- Cathodoluminescence
- Analysis of phosphors with spatial resolution on a nano scale

Learning objectives

The students
- know and understand basic concepts for the description of light
- understand basic concepts of the interaction of light with matter
- understand optical properties of semiconductor-nanomaterials
- know basics of plamonics
- know optical measurement techniques for the spectroscopic characterisation of single nano structure
- have an overview of high resolution optical microscopy
- have an overview of application of optical relevant nano materials

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Optical Litography: Technology, Physical Effects, and Modeling**
Topic(s):	Optical Material Processing Optical Materials and Systems
Coordinator(s):	PD. Dr. Andreas Erdmann
Lecturer(s):	PD. Dr. Andreas Erdmann

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Optical Litography: Technology, Physical Effects, and Modeling

Content

This course reviews different types of optical lithographies and compares them to other methods. The advantages, disadvantages, and limitations of lithographic methods are discussed from different perspectives. Important components of lithographic systems, such as masks, projection systems, and photoresist will be described in detail. Physical and chemical effects such as the light diffraction from small features on 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.

Learning objectives

The students should

- Understand the principles of optical projection lithography: image formation in projection optics, photoresists, lithographic process flows, process evaluation and resolution limits
- Learn how optical and material-driven resolution enhancements work: “tricks” of lithographers: optical proximity correction (OPC), phase shift masks, off-axis illumination, source-mask optimization, double exposure and double patterning, directed self-assembly
- Get an overview on alternative lithographic techniques: EUV lithography, interference lithography, contact- and proximity printing, near-field and STED-inspired lithography, e-beam lithography, nanoimprint
- Get an introduction to lithography simulation: aerial image calculation, resist modeling techniques, process analysis and optimization

Understand the role of nanoscale light scattering effects: rigorous electromagnetic field (EMF) simulation for advanced lithographic processes, mask- and wafer side topography effects

Literature

- Levinson H.J.: “Principles of lithography”, Third Edition, SPIE Press, 2010.
- Mack C.: “Fundamental principles of optical lithography”, John Wiley & Sons, 2007.
- Okoroanyanwu, U.: “Chemistry and lithography”, *SPIE Press,* **2011**

Lecture script of A. Erdmann will be distributed during the lecture

Prerequsites

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Exam: 30 min oral

Module name:	**Phosphors**
Topic(s):	Optical Materials and Systems
Coordinator(s):	Prof. Dr. Christoph J. Brabec
Lecturer(s):	PD Dr. Miroslaw Batentschuk

Duration:	1 semester	**ECTS:**	3	**SWS:**		**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	45 h				
Language:	English						

Lecture(s): Phosphors

Content

- Classification of phosphors
- Absorption and emission of light in phosphors
- Fluorescent and persitent nano markers
- Energy transmission als a basic for the development of new phosphors for white light LEDs
- Phosphor as converter for solar cells and the acceleration of plant growth
- Examples for new development of optical discs and storage phosphor
- Efficiency of anorganic phosphors (excitation of ionising radiation)
- Eu-ion as probe
- Identification of the colour coordinates of light sources

Learning objectives

The students are able to adapt her knowledge about physical and chemical properties of semiconductors and isolators and about the production of crystals to the evalution of different production methods and for the development of new technologies in the field of components and renewable energy technology.

Literature

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Prerequsites

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Exam: 40 min oral

Module name:	**Solar Energy**
Topic(s):	Optical Materials and Systems
Coordinator(s):	Prof. Dr. Christoph Pflaum
Lecturer(s):	Prof. Dr. Christoph Pflaum Prof. Dr. Christoph J. Brabec

Duration:	1 semester	**ECTS:**	5	**SWS:**	2	**Cycle**	WS and SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	30 h	**Self-study:**	12 h				
Language:	English						

Lecture(s): Solar Energy

Content

- Solar panel technology
- Organic solar cells, principles and manufacturing costs
- Silicon solar cell
- Novel materials for high-efficiency solar cells
- Thin film solar cells and nanoparticle
- Improvement of solar cells efficiency
- The effect of TCO on light trapping in silicon thin film solar cells
- Thin film solar cell production process
- Parabolic mirrors
- Solar cooling
- Solar power plants
- Hybrid/integrated energy systems
- Distributed energy generation
- Integration of distributed energy generation to the power grid
- Stability of power system and harmonics, power quality
- Electric converters and inverters (AC to DC and DC to AC)
- HVDC power transmission
- Smart grids
- Integrated solar cells on windows and buildings
- Overview of energy storage techniques
- Energy harvesting
- Micro- and nano-energy systems and technologies
- Energy and environmental effectst
- Overview of EMF simulation methods

Learning objectives

Students should

- know examples for the application of solar energy
- be able to do literature research in the field and to analyse the literature
- be able to develop a presentation in the field

Literature

References given in the lecture

Prerequsites

Basic knowledge in energy technology

Exam: Presentation

Module name:	**Advanced Optical Communication Systems**
Topic(s):	Optics in Communication and Information Technology
Coordinator(s):	Prof. Dr. Bernhard Schmauß
Lecturer(s):	Prof. Dr. Bernhard Schmauß

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Advanced Optical Communication Systems

Content

• multiplex techniques: electrical / optical time division multiplexing, wavelength division multiplexing
• dispersion management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems
• noise and power management: power budget, OSNR management, OSNR calculation
• management of nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons
• spectral efficiency: definition, techniques to increase spectral efficiency
• modulation formats: intensity modulation, multilevel transmission, CS-RZ, SSB transmission, DPSK, DQPSK, coherent transmission, coherent receiver architecture
optical regeneration: 2R-regeneration by nonlinearities, distributed regeneration, 3R-regeneration

Learning objectives

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 designs of optical transmission systems
• are able to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results
• are able to develop and evaluate optical communication links by using simulation tools

Literature

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

Prerequsites

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Exam: 30 min oral

Module name:	**Linear and non-linear fibre optics**
Topic(s):	Optics in Communication and Information Technology
Coordinator(s):	Prof. Dr. Bernhard Schmauß
Lecturer(s):	Prof. Dr. Bernhard Schmauß

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Linear and non-linear fibre optics

Content

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.

Learning objectives

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

Literature

- 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

Prerequsites

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Exam: 30 min oral

Module name:	**Nonlinear optics in 1D-photonic structures**
Topic(s):	Optics in Communication and Information Technology Physics of Light
Coordinator(s):	Prof. Dr. Nicolas Joly
Lecturer(s):	Prof. Dr. Nicolas Joly

Duration:	1 semester	**ECTS:**	5	**SWS:**	2	**Cycle**	not regulary
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						

Lecture(s): Nonlinear optics in 1D-photonic structures

Content

1. Generation of structured light
2. Measuring structured light at the nanoscale
3. Interaction of structured light with nanoscopic structures
4. Classical Applications of structured light
5. Classical correlations and quantum correlations in structured light
6. Generating quantum states of structured light
7. Structured light for quantum-inspired sensing
8. Tailoring the light field for efficient interaction with single atoms

Learning objectives

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

Literature

Will be provided individually for each talk.

Prerequsites

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Exam: 30 min oral, presentation

Module name:	**Optical Communication Networks**						
Topic(s):	Optics in Communication and Information Technology						
Coordinator(s):	Prof. Dr. Herbert Haunstein						
Lecturer(s):	Prof. Dr. Herbert Haunstein						
Duration:	1 semester	**ECTS:**	2,5	**SWS:**	2	**Cycle**	WS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						
Lecture(s):	Optical Communication Networks						

Content

- Applications and services / Topologies / Hierarchical structuring (access-, metro-, corenetworks) / Static and dynamic Demands on optical networks / Data transport protocols (TCP, Internet-Protocol) / Resource dimensioning, traffic theory, models and characterization
- Standards for optical transmission techniques
- Aggregation Networks (Ethernet (IEEE 802) / Passive Optical Networks, PONs)
- Optical Networks, Transport Networks
- Synchronous Digital Hierarchy (SDH), Synchronous Optical Networks (SONET) / Optical Transport Network (OTN) / Multi-Protocol-Label-Switching MPLS (RFC 3031) Network Operation and Administration
- Components for Optical Transport Networks (long haul networks)
- Transmitter / receiver, wavelength multiplexer, optical amplifiers / Optical switches, tunable optical filters, dispersion compensation
- Introduction to optical transmission, optical interfaces / Single- and multi-channel systems, optical switching / Optical transparency, limiting effects, network monitoring

Learning objectives

The students are able to
- describe basics of optical networks and the demands on them
- explan the standards of optical transmission technology
- evaluate functional components of optical transport networks
- investigate and evaluate trends of future fiber optics networks

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Quantum Optics**
Topic(s):	Optics in Communication and Information Technology Physics of Light
Coordinator(s):	Prof. Dr. Gerd Leuchs
Lecturer(s):	Lecturers of the Physics Department

Duration:	4 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	not regulary
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						

Lecture(s): Quantum Optics

Content

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

Learning objectives

Students

- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

- Goodman: Statistical optics
- Mandel & Wolf: Optical coherence and quantum optics
- Klyshko: Physical foundations of quantum electronics

Scully & Zubairy: Quantum electronics

Prerequsites

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Exam: 5

Module name:	**Computational Optics**
Topic(s):	Computational Optics
Coordinator(s):	Prof. Dr. Christoph Pflaum
Lecturer(s):	Prof. Dr. Christoph Pflaum

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	45 h	**Self-study:**	105 h				
Language:	English						

Lecture(s): Computational Optics

Content

The lecture focuses on two applications:
- numerical simulation of lasers
- numerical simulation of optical waves in thin film solar cells

Subjects:
- **Introduction to Computational Optics**
- **Basic Physical Equations:** Maxwell's Equations and Helmholtz's Equation, Refraction Indices, Time Periodic Solutions,
- **Solving Maxwell's Equations:** Finite Difference Time Domain Discretization (FDTD), Stability of FDTD, Implementation of the FDTD Method, Simple Boundary Condition, PML Boundary Condition, Incoming Boundary Condition with PML, Calculation of Time Periodic Solutions, Stable Iteration Method for Negative Permittivity, Finite Integration
- **Beam Propagation**: Paraxial Approximation, Beam Propagation Method
- **Basic Properties of a Laser:** Elements of a Laser, Atomic Energy Levels, Spontaneous Emission and Stimulated Transition, Pumping Process and Population Inversion, Rate Equations of Four Level Laser, Laser Amplification and Oscillation Condition
- **Numerical Discretization of a Scalar Rate Equation**
- **Mode-Analysis:** Gauss Mode Analysis (the Lowest Order Gauss-Mode, Gauss Mode in an Aperture, ray Optics and ABCD Matrix, ABCD Matrix of free space, ABCD Matrix of a lense, ABCD Matrix of a Mirror, Other ABCD Matrices, Ray (or Beam) Matrix of the Resonator, Exact Solution in a Gaussian "Duct", The Guoy Phase Shift, High Order Modes, Thermal Lensing), Iteration Method of Fox and Li

Output Power of a Laser

Learning objectives

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

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Diagnostical Medical Image Processing (lecture only)**
Topic(s):	Computational Optics Optics in Medicine
Coordinator(s):	Prof. Dr. Andreas Maier
Lecturer(s):	Prof. Dr. Andreas Maier

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	3 h	**Exercise/week:**	1 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Diagnostical Medical Image Processing (lecture only)

Content

The contents of the lecture comprise basics about medical imaging modalities and acquisition hardware. Furthermore, details on acquisition-dependent preprocessing are covered for image intensifiers, flat-panel detectors, and MR. The fundamentals of 3D reconstruction from parallel-beam to cone-beam reconstruction are also covered. In the last chapter, rigid registration for image fusion is explained.

Learning objectives

- understand the challenges in interdisciplinary work between engineers and medical practitioners.
- develop understanding of algorithms and math for diagnostic medical image processing.
- learn that creative adaptation of known algorithms to new problems is key for their future career.
- develop the ability to adapt algorithms to different problems.
- are able to explain algorithms and concepts of the lecture to other engineers.

Literature

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Prerequsites

Mathematics for engineers

Exam: 120 min written

Module name:	**Image Processing in Optical Nanoscopy**
Topic(s):	Computational Optics Optics in Medicine
Coordinator(s):	PD Dr. Harald Köstler
Lecturer(s):	PD Dr. Harald Köstler

Duration:	1 semester	**ECTS:**	5	**SWS:**	2	**Cycle**	SS
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						

Lecture(s): Image Processing in Optical Nanoscopy

Content

The module includes two interlinked topics. First, an introduction to the techniques of optical imaging (e.g. for biological specimen) with a special focus on recently evolving super-resolution techniques beyond the diffraction barrier. Second, the students will be given an overview of existing numerical techniques in imaging processing especially for image deblurring. The focus lies on algorithms based on FFT, energy minimization, and sparse coding. Additionally one makes use of information about the imaging system. The algorithms are applied to optical imaging and implemented in Matlab.

Learning objectives

- Implementing algorithm for image processing in Matlab
- Differentiate various methods of high-resolution microscopy
- Validate algorithm of image processing against actual data

Literature

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Prerequsites

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Exam: 30 min oral, presentation

Module name:	**Interventional Medical Image Processing**					
Topic(s):	Computational Optics Optics in Medicine					
Coordinator(s):	Prof. Dr. Andreas Maier					
Lecturer(s):	Prof. Dr. Andreas Maier					
Duration:	1 semester	**ECTS:** 5	**SWS:** 4	**Cycle** SS		
Lecture/week:	3 h	**Exercise/week:** 1 h				
Classes:	60 h	**Self-study:** 90 h				
Language:	English					
Lecture(s):	Interventional Medical Image Processing					

Content

This lecture focuses on recent developments in image processing driven by medical applications. All algorithms are motivated by practical problems. The mathematical tools required to solve the considered image processing tasks will be introduced.
The lecture starts with an overview on pre-processing algorithms such as scatter correction for xray images, edge detection, super-resolution and edge-preserving noise reduction. The second chapter describes automatic image analysis using feature descriptors, key point detection, and segmentation using bottom-up algorithms such as the random walker or top-down approaches such as active shape models. Furthermore, the lecture covers geometric calibration algorithms for single view calibration, epipolar geometry, and factorization. The last part of the lecture covers non-rigid registration based on variational methods and motion-compensated image reconstruction.

Learning objectives

The participants
- summarize the contents of the lecture.
- apply pre-processing algorithms such as scatter correction and edge-preserving filtering.
- extract information from images automatically by image analysis methods such as key point detectors
- and segmentation algorithms.
- calibrate projection geometries for single images and image sequences using the described methods.
- are able to develop non-rigid registration methods using variational calculus and different regularizers.
- adopt algorithms to new domains by appropriate modifications.
- implement the algorithms that were covered in the exercises.

Literature

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Prerequsites

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Exam: 60 min written

Module name:	**Pattern Analysis**
Topic(s):	Computational Optics
Coordinator(s):	Prof. Dr. Andreas Maier
Lecturer(s):	Prof. Dr. Andreas Maier

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	SS
Lecture/week:	3 h	**Exercise/week:**	1 h				
Classes:	80 h	**Self-study:**	70 h				
Language:	English						

Lecture(s): Pattern Analysis

Content

Based on the lecture Pattern Recognition, this lecture introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods. The lecture comprises:

- an overview over regression and classification, in particular the method of least squares and the Bayes classifier
- clustering methods: soft and hard clustering
- classification and regression trees and forests
- parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximuma-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees
- mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking
- linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), local linear embedding (LLE), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps
- Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/Viterbi algorithm, forward-backward algorithm, scaling
- Bayesian networks
- Markov random fields (MRF): definition, probabilities on undirected graphs, Hammersley-Clifford theorem, cliques, clique potentials, examples for MRF-based image pre-processing and processing of image sequences
- Markov random fields and graph cuts: sub-modular functions, global optimization with graph cut algorithms, application examples

Learning objectives

The students

- explain the discussed methods for classification, prediction, and analysis of patterns
- define regression and classification tasks as optimization problems
- understand joint discrete and continuous optimization and relaxation by transformation of discrete variables into continuous variables, e.g. from {0,1} to [0,1]
- 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 sequence

Literature

- Christopher Bishop, Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006
- Richard O. Duda, Peter E. Hart und David G. Stork, Pattern Classification, Second Edition, 2004
- Trevor Hastie, Robert Tibshirani und Jerome Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Second Edition, Springer Verlag, 2009

Prerequsites

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Exam: 30 min oral

Module name:	**Pattern Recognition**
Topic(s):	Computational Optics
Coordinator(s):	Prof. Dr. Elmar Nöth
Lecturer(s):	Prof. Dr. Elmar Nöth

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	WS
Lecture/week:	3 h	**Exercise/week:**	1 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Pattern Recognition

Content

- 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

Learning objectives

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

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Advanced Course in Experimental Physics: Lasers, Atomic Physics and Quantum Optics**
Topic(s):	Physics of Light
Coordinator(s):	Prof. Dr. Joachim von Zanthier
Lecturer(s):	Prof. Dr. Joachim von Zanthier

Duration:	1 semester	**ECTS:**	10	**SWS:**	6	**Cycle**	WS
Lecture/week:	4 h	**Exercise/week:**	2 h				
Classes:	90 h	**Self-study:**	210 h				
Language:	English						

Lecture(s): Advanced Course in Experimental Physics: Lasers, Atomic Physics a

Content

- Wave optics: Gaussian beams, ABCD matrices, diffraction
- Light propagation in media
- Complex index of refraction, photonic materials, dispersion
- Coherence
- Light-matter interaction: Classical description, 2-state quantum systems, stimulated emission
- Laser: Types of lasers, dynamics of lasers, rate equations
- Laser spectroscopy
- Nano-optics
- Laser cooling and trapping of atoms
- Bose-Einstein condensation
- Introduction to quantum optics
- Strong-field physics

Learning objectives

Students
- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

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Prerequsites

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Exam: 120 min written

Module name:	**Modern Optics I: Advanced Optics**
Topic(s):	Physics of Light Optical Metrology
Coordinator(s):	Prof. Dr. Nicolas Joly
Lecturer(s):	Prof. Dr. Nicolas Joly

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	not regulary
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Modern Optics I: Advanced Optics

Content

- 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.

Learning objectives

Students
- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

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Prerequsites

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Exam: 120 min written

Module name:	**Non-linear Optics**
Topic(s):	Optics in Communication and Information Technology Physics of Light
Coordinator(s):	Prof. Dr. Nicolas Joly
Lecturer(s):	Prof. Dr. Nicolas Joly

Duration:	1 semester	**ECTS:**	5	**SWS:**	4	**Cycle**	not regulary
Lecture/week:	2 h	**Exercise/week:**	2 h				
Classes:	60 h	**Self-study:**	90 h				
Language:	English						

Lecture(s): Non-linear Optics

Content

- Linear properties of materials.
- Origin of the nonlinear susceptibility.
- Importance of phase-matching.
- Second harmonic generation, derivation of the set of coupled equations.
- Importance of the initial phase and case of seeding second harmonic generation. Use of birefringence to achieve phase-matching.
- Electro-optic effects.
- Nonlinear process in relation to third order nonlinearity.
- Modulation instability, soliton formation, perturbations of soliton, and supercontinuum generation.
- Application: nonlinear optics in photonic crystal fibers.

Learning objectives

Students
- explain the relevant topics of the lecture
- apply the methods to specific examples

Literature

- Paul Mandel : Nonlinear Optics (Wiley-VCH 2010)
- Robert Boyd: Nonlinear Optics (Academic Press, 2008)
- Geoffrey New: Introduction to nonlinear optics (Cambridge University Press, 2011)

Prerequsites

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Exam: 30 min oral

Module name:	**Quantum and classical experiments with structured light**
Topic(s):	Optical Materials and Systems Physics of Light
Coordinator(s):	Prof. Dr. Gerd Leuchs
Lecturer(s):	Dr. Peter Banzer Dr. Christoph Marquardt

Duration:	1 semester	**ECTS:**	5	**SWS:**	2	**Cycle**	not regulary
Lecture/week:	2 h	**Exercise/week:**	h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						

Lecture(s): Quantum and classical experiments with structured light

Content

1. Plasma in fibre (modeling and experiment)
2. Processes involved in supercontinuum generation
3. Generation of correlated photons: crystal vs. fibers based systems
4. Dynamics of Raman fiber laser
5. Use of Raman-active gases for nonlinear optics in fibre
6. Harmonic generation in whispering gallery mode cavity
7. Optomechanics effect vs. Kerr-effect: a fair comparison?
8. Generation of frequency comb
9. Use of resonance in WGM resonator

Learning objectives

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

Literature

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Prerequsites

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Exam: 30 min oral

Module name:	**Lab courses**
Topic(s):	Topics
Coordinator(s):	Prof. Dr. Bernhard Schmauß
Lecturer(s):	Dr. Christoph Horneber Dr. Bernhard Michel Matthias Bär Felix Tenner Thomas Koller Dr. Maximilian Rohde Dr. Daniel Gilbert

Duration:	1 semester	**ECTS:**	5	**SWS:**	5	**Cycle**	WS and SS
Lecture/week:	0 h	**Exercise/week:**	2 h				
Classes:	30 h	**Self-study:**	120 h				
Language:	English						

Lecture(s):
Lab course "Optical Metrology
Lab course "Optical Material and Processing"
Lab course "Computational Optics"
Lab course "Optics in Medicine"
Lab course "Optical Material and Systems"
Lab course "Optics in Communication"
Lab course "Physics of Light"

Content

The lab courses cover experiments or tasks which are exemplatory or central for the topic.

Learning objectives

The students learn how to conduct an experiment, how to analyse data and how to put that in a report.

Literature

will be given in the lab course

Prerequsites

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Exam: Lab reports for two courses