Ph.D. Program Guidebook

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1 Research Areas of KSOP

The four anticipated KSOP research areas are organized according to the needs in education and the existing strengths of the research programs at the Universität Karlsruhe (TH). We have structured KSOP along the following four research areas**: Photonic Materials & Devices, Advanced Spectroscopy, Biomedical Photonics and Optical Systems**. All research areas are strongly interlinked and most institutes feature research projects in more than one of the research areas. The following paragraphs give a brief introduction into these research areas.

1.1 Research Area I: Photonic Materials & Devices

Novel materials and devices are the driving force for novel applications and they are at the focus of interest in basic research. Materials and devices for exploring solid state quantum computing and cryptography phenomena are amongst the hottest topics in condensed matter physics. Materials with unforeseen linear and nonlinear optical properties are fascinating fields of current research, both from a basic as well as from an application-oriented point of view. Often driven by the industry's need to reduce costs, materials- and synthesis- and deposition-technologies that are more cost effective compared to the existing approaches have to be explored. Metamaterials, photonic crystals and unconventional low-cost nano-materials with novel optical and optoelectronic functionalities are examples for the Karlsruhe based activities in this research area.

1.2 Research Area II: Advanced Spectroscopy

Advanced spectroscopy in general is a unique tool for unraveling novel quantum and nonlinear optical phenomena and to study the fundamental electronic properties of existing and artificial materials. Ultrafast and highly spatially resolved spectroscopy is established in several institutes. Here the spectroscopic techniques are essential for pushing the limits of research objectives in the field of materials and devices. Moreover, advanced spectroscopy is also indispensable as a tool for studying the basic phenomena and strategies for the optimization of widely used technical processes. A particularly prominent example is the research on combustion phenomena. Using different spectroscopic and imaging techniques optical instrumentation is essential in the development of energy efficient processes. Often a novel spectroscopic technique is the method of choice in a sensor system which in turn is part of a bigger optical system (see research area IV).

1.3 Research Area III: Biomedical Photonics

Optics and photonics have paved the way for progress in many realms of modern medicine and biology. Advances in microscopy were and are driven by the needs of the life sciences. Minimally invasive surgery is only possible through the use of advanced lasers and compact imaging systems. Noninvasive monitoring of essential bodily functions such as glucose sensing will most likely be one the strongest growing applications of optical sensors. In basic research as well as drug discovery optical technologies have become essential. Progress in genomics and proteomics relies on novel and massively parallel optical methods for the detection of biochemical reactions. Nano-photonics is the key for advances in the field of high-throughput screening.

1.4 Research Area IV: Optical Systems

In the majority of applications, optical and optoelectronic components are key parts of larger entities. Optical systems are found in advanced photonic micro-systems in sensing technologies, in industrial systems for metrology and machining and in globally connected optical networks that provide the information backbone for our society. The demands for these systems are ever increasing. It is not only the research on faster, more sensitive and more powerful components that is required to fulfill the future demands. System and software engineering issues are becoming more and more important to harvest the potential that is offered by the progress in components.

2 Research Training

The candidates who are accepted as Ph. D. students within KSOP will not only be part of an excellent research environment but will also be trained in a well balanced and structured manner. While the main focus of the Ph.D. training lies on the graduate student **research** work we are convinced that additional elements in the doctoral training are needed to reach the optimum academic success and to develop leadership capabilities. In order to achieve valuable scientific results, the talented Ph.D. student needs to **acquire knowledge** and he/she is required to **exchange knowledge and experience** with other Ph.D. students as well. **Supervision** by two advisors and one mentor accompany the whole doctoral thesis work to ensure the constant quality of the work and so its success. In order to achieve and maintain a high level of Ph.D. theses in general, a **total quality management** program will be practiced and implemented by the managing administrator of KSOP. The different instruments aim at an efficient and successful scientific research work, a finalization of the thesis within **three years** and the acquisition of interdisciplinary elements of knowledge and key competences for a career as an academic or industrial leader.

We have elaborated several different components for improving the doctoral education. In the **KSOP doctoral program** the active participation is mandatory. These elements are brought to reality by:

1) the continuous advice by two professors,

2) a monthly mentoring meeting with the respective young scientist (mentor) of the research area,

3) a monthly participation in at least one method-oriented working group,

4) the successful participation in *five* two-week elite Ph.D. course modules (with a minimum of one module in each of the different categories *technical*, *scientific* and *management*),

5) an annual presentation during the “Karlsruhe Days of Optics” and

f) the excellent research infrastructure at the Universität Karlsruhe (TH).

The following scheme exemplifies how the different measures apply during the process of the doctoral thesis. The Ph.D. student is assumed to perform her/his doctoral research work in the research area **“Advanced Spectroscopy”.** During the three years, the student has to complete five modules, choose a working group and present her/his results during the “Karlsruhe Days of Optics” three times.

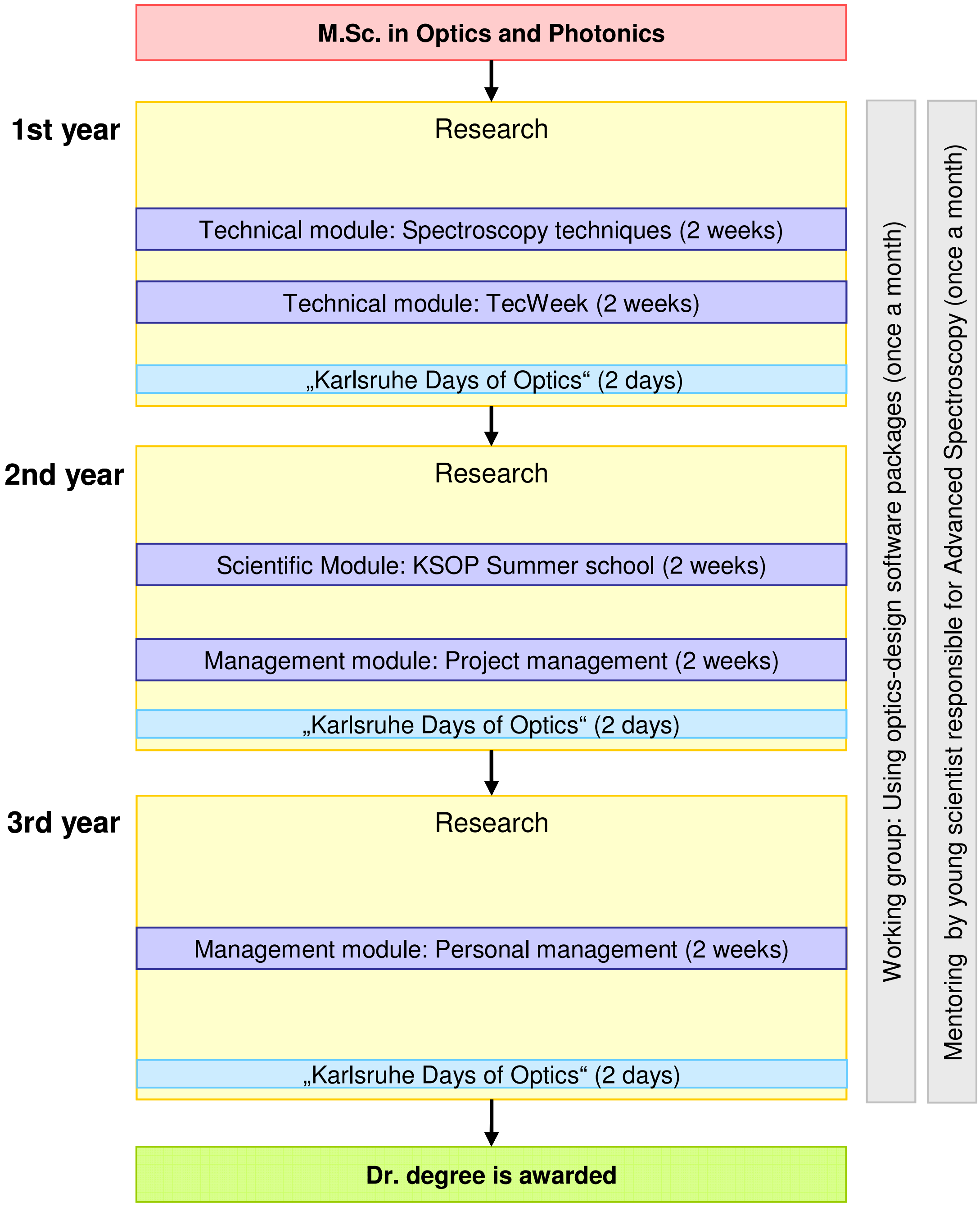

Fig. 1: Exemplary process of Ph.D. thesis

Within the present structure of the Universität Karlsruhe (TH), the Ph.D. degree will be awarded to KSOP students by the corresponding departments. The choice regarding the degree aimed for has to be made at the beginning of the thesis by the candidate, in agreement with the two advisors, preferably chosen from two *different* departments. The degrees "Dr. rer. nat." or "Dr.-Ing." are currently possible. However, within the framework of the excellence initiative, the structure of the Universität Karlsruhe (TH) will change considerably throughout the next years. Our long-term vision is to establish a Ph.D. degree in Optics and Photonics, awarded by the KSOP.

2.1 Graduate Student Research Work

The Ph.D. will be awarded to KSOP students who have demonstrated excellence in their own research work. Each Ph.D. student will strive for new scientific results in the area of her/his thesis subject. The research that shall be conducted autonomously by the student comprises literature research, planning and conducting suitable research projects and analyzing the achieved results. The research work will be accompanied by discussions with the advisors, the mentor, and the working group, respectively. The working group will help to get started with the necessary equipment and software. The advisors, the mentor and informal working groups consisting of different scientists and students will support the student in identifying problems and finding appropriate solutions during all phases of the research work.

Potential thesis subjects for candidates of the new Ph.D. program can be grouped according to the four research areas.

2.2 Acquisition of Knowledge (Elite Ph.D. Course Modules)

The regular attendance of all relevant research seminars and relevant colloquia of the respective department is expected from each Ph.D. student. However, the regular attendance of university lectures – which also requires additional efforts – can sometimes interfere with the research activities of the Ph.D. students. We therefore favor a well structured program of different modules for the Ph.D. training. This is in agreement with the concepts of professional training in an industrial context and it also supports networking of the Ph.D. students. Most of the modules are designed for a two-week phase of intense interactive learning. As a mandatory level of **technical**, **scientific** and **management** skills, modules equivalent to five two-week sessions have to be taken and documented by the candidates. A broad education is ensured by the requirement that at least one module out of each category “technical”, “scientific” and “management” has to be completed. In addition, depending on their backgrounds and interests, students may be advised to attend specific lecture courses from the KSOP masters program.

2.3 Technical Modules

Ph.D. students who have either graduated in our own M.Sc. program or have been accepted to the Ph.D. program after graduation in an appropriate Masters or Diploma program are expected to have a solid theoretical and experimental optics and photonics education. Based on our own experience with many Ph.D. students, “training on the job” is very important in science (similar to a young professional entering a company). Thus, we have worked out a catalogue of mainly two-week modules bringing Ph.D. students from different institutes into contact with each other and providing them with “hands-on” knowledge on special experimental and/or computational methods. This will ensure a quick start into productive research work and will strengthen the awareness and independence of doctoral students. It will develop their ability to make critical judgments and apply various perspectives to their research problems. The interaction with other Ph.D. students in this early stage of the thesis will also ensure networking of the “fresh” students with the colleagues from other institutes.

The following two-week technical skills modules will be offered for structured introduction into successful research work in the four respective areas. The training modules are mainly conducted by the young scientist who coordinates the respective research area. The following table lists the modules that are currently planned:

Research area	Course	Content
I: Photonic Materials & Devices	Nanotechnology laboratory	Introduction into working in a clean-room environment, photo-lithography, thin-film deposition
II: Advanced Spectroscopy	Laser laboratory work	Laser safety, principles of laser laboratory work and aligning procedures
	Techniques of spectroscopy	Practical work with different spectroscopy systems

III: Biomedical Photonics	Advanced light microscopy in biological sciences	Preparation of biological samples, fluorescence microscopy, live cell imaging, laser scanning microscopy
IV: Optical Systems	Digital signal processing	Computer lab training for the introduction into different image processing strategies
	Computer aided design of optical and photonics systems	Computer lab training for the introduction into different optical design software packages
General (one week courses)	LabView	Data acquisition and hardware control using LabView
	MatLab/SimuLink	Data evaluation, numerics using MatLab and systems modeling using SimuLink

2.3.1 Laser Laboratory Work

Lasers play a central role in a broad range of fields in science and engineering. We also consider the laser as a key tool for all research areas. Thus, an advanced understanding of laser physics as well as practice in laser laboratory work is of utmost importance for all Ph.D. students of the “Karlsruhe School of Optics & Photonics”.

The technical module “Laser Laboratory Work” will provide the Ph.D. students with the necessary skills for the daily work with lasers in the lab. In combination with the technical module “Spectroscopy techniques” it will enable the Ph.D. students to plan and set up their own experiments for their research projects.

The main emphasis of this technical module will be to provide “hands-on” knowledge of laser laboratory work and aligning procedures. For this purpose, a good deal of time will be dedicated to the set up and alignment of a laser from scratch. Afterwards, different techniques for the characterization of laser beams and pulses will be demonstrated. The lab work is accompanied by lectures on laser safety and laser physics which will provide (or refresh) the necessary theoretical background. The technical module will be completed by lab tours in which the Ph.D. students are shown how lasers are used in different groups of the Universität Karlsruhe (TH).

TECHNICAL MODULE: Laser Laboratory Work	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: laser safety	Aspects of laser safety including state regulations
Lecture: basic laser theory	Principles of lasers physics, electromagnetic modes in a laser, overview of different types of lasers
Look in the lab	Presentation of the problem: set up and alignment of a laser; correct handling of the pump laser
Day 2	
Lecture: laser design	Principles of optical resonators, stability criteria, resonance frequencies, losses in optical resonators
Lab work:	Set up and alignment of a laser
Day 3 to 7	
Lab work:	Set up and alignment of a laser
Day 8	
Lecture: pulsed lasers	Theory of pulsed lasers, Q-switching, mode locking, dispersion compensation, characterization of ultrashort optical pulses
Lab work:	Measurement of the autocorrelation of a femtosecond laser, determination of the time-bandwidth product
Day 9	
Lecture: other coherent light sources	Elements of nonlinear optics; theory of optical parametric oscillators (OPOs), and optical parametric amplifiers (OPAs)
Look in the lab	The OPO: a tunable coherent light source
Day 10	
Lab tours	Lasers as tools for different applications in science and engineering

2.3.2 Nanotechnology Laboratory

In the research area **Photonic Materials & Devices** we will offer a hands-on experience in a cleanroom environment. Starting from raw materials it needs a large number of process steps to end up with an optoelectronic device like a solar cell or a semiconductor laser diode. The fabrication of an optoelectronic device has to be performed in certain successive fabrication steps determined by a number of individual technological constraints. Each critical fabrication step is followed by a suitable characterization to achieve a high yield of the total fabrication procedure.

The technical module "Nanotechnology Laboratory" will provide the Ph.D. students with the necessary skills for the daily work in a cleanroom with standard fabrication and characterization techniques. It will enable the Ph.D. students to determine suitable fabrication processes for novel device structures and optimize the required process parameters. The main emphasize of this technical module will lie on "hands-on" knowledge. For this purpose, a series of standard fabrication techniques will be shown, aiming at the fabrication of three different optoelectronic components: an organic solar cell, an organic laser and a metal-semiconductor-metal photodetector. The work is accompanied by lectures covering the theoretical background of the particular fabrication steps, general aspects of a cleanroom facility and safety issues. In addition to the machines used for the fabrication of the three optoelectronic components, other major machines and pieces of equipment at the different labs of the Universität Karlsruhe (TH) will be explained in the context of current research projects. This includes also the advanced equipment available at the CFN Nanostructure Service Laboratory.

TECHNICAL MODULE: Nanotechnology Laboratory	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: cleanroom concepts and safety measures	Aspects of particle contamination, purity of process materials, protection of the samples as well as technologists' health
Lecture: solar cells	Principles of different inorganic and organic solar cells, overview of different layouts, efficiencies and fabrication costs
Day 2	
Lab work:	Preparation of substrate materials for organic solar cells: transparent conducting material ITO, measurement of conductivity, introduction to surface plasma treatment
Lab work:	Preparation of layers for organic solar cells by means of spin-coating
Lecture: evaporation techniques	Principles and constraints of different evaporation techniques and materials classes using thermal evaporation, sputter deposition, electron gun evaporation and chemical vapor deposition

TECHNICAL MODULE: Nanotechnology Laboratory	
Parts of the course	**Content (selected keywords)**
Day 3	
Lab work:	Evaporation of metallic electrodes for the solar cells
Lecture: spectroscopic characterization of solar cells	Theoretical background for quantitative measurements of quantum efficiencies, transport properties and spectral response of solar cells
Lab work:	Electrical contacting and mounting of solar cells in the characterization chamber
Day 4	
Lab work:	Measurement of the solar cell's performance
Lecture: semiconductor lasers	Theory of different types of semiconductor laser structures, inorganic and organic
Day 5	
Lab work:	Fabrication of a substrate for an organic DFB laser using interference lithography
Lab work:	Optical characterization of the fabricated grating by measuring the diffraction efficiency
Day 6	
Lab work:	Deposition of active organic materials for a DFB laser
Lab work:	Characterization of lasing properties (threshold, emission wavelength and profile)
Day 7	
Lecture: photodetectors	Theory of photodetectors, dynamic response and quantum efficiency, different concepts
Lecture: photolithography	Theory of photoresists, photochemical reactions, mask aligners and optical mask technology
Lab work:	Photolithography, patterning of metallic contacts
Day 8	
Lab work:	Fabrication of metallic electrodes for MSM-photodetectors
Lecture: etching techniques	Theory of wet and dry etching techniques of semiconductors
Lab work:	Lithography and patterning of mesa-structures
Lab work:	Electrical contacts using bond techniques

TECHNICAL MODULE: Nanotechnology Laboratory	
Parts of the course	**Content (selected keywords)**
Lab work:	Optical characterization of the static properties of the MSM-photodetector
Lab work:	Optical characterization of the dynamic properties of the MSM-photodetector
Day 9	
Lab tour	Facility for fabrication of micro- and nanoelectronic structures at CFN
Day 10	
Lab tour	Electron microscopic techniques (SEM, TEM, FIB)

2.3.3 Techniques of Spectroscopy

The choice of the right detector often is the choice between failure or success of an optical experiment. Today's optical experiments are challenging in (i) their need to detect low light levels, e.g., in single-object spectroscopy, (ii) their need of high signal-dynamics, e.g., in interferometric experiments, and (iii) their need of resolving fast and ultra-fast signals. This course introduces Ph.D. students into various aspects of today's measurements of light.

The first week combines lectures in the morning with visits of laboratories in the afternoon. The lectures in this part of the course lay the theoretical foundation behind different detection techniques, while the laboratory visits suit as a demonstration how these techniques are applied in various groups within the framework of the Karlsruhe School of Optics & Photonics. The second week is dedicated to hands-on practice. The Ph.D. students will learn (i) how to operate a state-of-the-art liquid-nitrogen cooled CCD-camera system in combination with an imaging spectrograph and (ii) how to plan, set up and align a Fourier-Transform-Spectrometer for measurements in a broad spectral range with high signal dynamics.

TECHNICAL MODULE: Techniques of Spectroscopy	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: Introduction	Detection techniques, underlying principles in semiconductor

	and metal physics, photon counting, cooling of detectors
Lecture: Amplification	Principles and interplay of different amplification schemes: Signal amplification *via* photon/electron multiplication, Lock-in amplification, Current pre-amplification, Voltage amplification
Lecture: Noise and background	Types and sources of noise, fundamental limitations, elimination and/or suppression of backgrounds
Day 2	
Lecture: Photomultiplier	Principles and physics of PMs, PMs for the visible and near-infrared, photon counting with PMs, time response
Look in the lab	Selected examples of experiments involving photomultipliers
Day 3	
Lecture: Photodiodes	Principles and physics of semiconductor PDs, materials, influence of detector size, spectral range, sensitivity, cooling, time response
Look in the lab	Selected examples of experiments involving photodiodes
Day 4	
Lecture: CCD cameras	Principles and physics behind charge-coupled-devices, read-out and addressing, binning, noise, sensitivity, spectral range, spectrographs
Look in the lab	Selected examples of experiments involving CCD cameras
Day 5	
Lecture: Streak cameras	principles and physics behind streak-cameras, time resolution, detection
Look in the lab	Selected examples of experiments involving streak cameras
Day 6 to 8	
Hands on: CCD camera	Setup of a PL detection experiment: Alignment, calibration, error sources, WinSpec and LabView, comparison with point detectors
Day 9 to 10	
Hands on: Fourier-Transform spectrometer	Setup of a fourier transform spectrometer: Alignment, calibration choice of optical components, choice of detector

2.3.4 Advanced Light Microscopy in Biological Sciences

During the last decade light microscopes have evolved from simple imaging devices to modern laboratory tools capable to analyze dynamic properties of molecules in living tissue and to manipulate living cells. Major driving forces behind this development have been new imaging techniques in synergy with the generation of a plethora of fluorescent probes that make it possible to label cellular organelles or proteins with high specificity. Thus, an understanding of advanced imaging techniques in modern life sciences as well as practical laboratory work is of importance for Ph.D. students of the “Karlsruhe School of Optics & Photonics”.

The technical module “Advanced Light Microscopy in Biological Sciences” will provide the Ph.D. students with necessary skills for the daily work with state-of-the-art microscopes. The Ph.D. students will prepare different biological samples for their training on the microscopes. The practical part will include fluorescence microscopy, live-cell imaging, and laser scanning microscopy (LSM). The lab work is accompanied by lectures on fundamentals of microscope optics and fluorescence microscopy with emphasis on the theory of laser scanning microscopy.

TECHNICAL MODULE: Advanced Light Microscopy in Biological Sciences	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: fundamentals of microscope optics	Aspects of principal microscope optics and generation of image contrast
Lecture: fundamentals of fluorescence	Aspects of fluorescence microscopy and fluorescent probes
Lab tour	Presentation of microscopes and cell culture equipment
Day 2	
Lecture: biological sample preparation	Fixation, staining and embedding procedures
Lab work: sample preparation	Cell culture and immunostaining
Day 3	
Lecture: light detectors	Photomultiplier tubes, video systems, CCD-cameras
Lab work: sample preparation	Cell culture and immunostaining continued
Day 4	
Lecture: Laser scanning microscopy	Theory and principles of LSM

TECHNICAL MODULE: Advanced Light Microscopy in Biological Sciences	
Parts of the course	**Content (selected keywords)**
Lab work: fluorescence microscopy	Microscopy of immunostained samples
Day 5	
Lecture: Laser scanning microscopy 2	Quantitative and analytical techniques in LSM
Lab work: fluorescence microscopy	Microscopy of immunostained samples
Day 6 - 8	
Lab work: Laser scanning microscopy and live cell imaging	LSM with own biological samples, cell culture for live cell imaging
Day 9	
Lecture: advanced image processing	Quantitative and analytical techniques during image processing
Lab work: Laser scanning microscopy and digital image processing	LSM with own biological samples, cell culture for live cell imaging
Day 10	
Lab work: digital image processing	Computer work with obtained images

2.3.5 Computer Aided Design of Optical and Photonic Systems

Expert knowledge of state-of-the-art techniques for numerical simulation, modeling and design of devices is a key qualification for both, theoretically or experimentally oriented scientists and engineers. Numerical methods are indispensable in all fields ranging from basic research to product development. Therefore, the Ph.D.-program of the Karlsruhe School of Optics & Photonics provides a hands-on module geared towards familiarizing the students with various numerical approaches and their respective realm of applicability. The lectures are closely interwoven and supported by computer-lab modules, where a deeper understanding of the methods is developed and hands-on experiences with realistic applications are conveyed to the students. In addition to an understanding of the theoretical basis of the methods, insights into merits and limitations of the different approaches shall be fostered. Furthermore, essential aspects of practical relevance such as convergence, runtime considerations and resource management will be addressed. After completing this module, the student will have obtained an overview over the most widespread approaches, will have developed a basic understanding of their theoretical foundations, and will be in a position to select the appropriate method for a given problem.

Naturally, in this module the most important methods for treating general photonic and optical devices are especially highlighted. The two main pillars of this module are (i) aspects of simulation, i.e., the numerical solution of Maxwell's equations with standard (commercially available) as well as novel approaches, and (ii) design and optimization of devices. In both parts the knowledge acquired is instantly applied to illustrative problems in simulation and design that cover such diverse areas as the simulation of photonic crystals and organic semiconductor lasers, the design and simulation of thin film stacks with state-of-the-art software tools.

TECHNICAL MODULE: Computer Aided Design of Optical and Photonic Systems	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: Introduction to numerical methods.	Principles and overview of numerical methods, convergence, numerical dispersion, runtime and resource considerations
Lecture: Ray-optics and ray tracing	Principles of ray tracing, possibilities and limitations of software using ray-optics
Day 2	
Computer lab: Ray-tracing	Simulation and analysis of simple optical systems, interdependence between geometrical und material parameters
Day 3	
Lecture: Transfer matrix methods	1-dimensional problems, transfer matrices, ABCD- matrices in ray optics
Computer lab: Design of thin film stacks	Implementing a transfer-matrix calculation for solving 1-dimensional problems using MATLAB©
Day 4	
Lecture: Optimization	basic considerations, methods: line search, gradient descent, Newton's method, conjugate gradients method, Lagrange multipliers, simulated annealing
Computer lab: Simulation	Design and optimization of an organic semiconductor laser

TECHNICAL MODULE: Computer Aided Design of Optical and Photonic Systems	
Parts of the course	**Content (selected keywords)**
of semiconductor lasers	
Day 5	
Lecture: System level simulations	Mixed-level and mixed-domain modeling and simulation, Linear and nonlinear models of optical components
Computer lab: Simulation of optical communication system	Modeling of systems with sender, fiber link, and receiver in RSoft OptSim
Day 6	
Lecture: Rigorous coupled wave analysis (RCWA) for diffractive optics	Fourier factorization, transfer matrix and scattering matrix algorithm, reduction of complexity through symmetry considerations
Computer lab: RCWA for high-index and metallic structures	Convergence study for strongly scattering systems, stability of algorithms, near and far-field behavior, blazing
Day 7	
Lecture: Finite elements	Variational formulation of wave equations and incorporation of boundary conditions, meshing of computational domains, matrix assembly, fast solvers for sparse matrix problems
Computer lab: Whispering gallery modes	Implementation of a complex structure (micro-disk resonator on a pedestal), eigenmodes and their quality factors (finesse)
Day 8	
Lecture: Finite-Difference Time-Domain (FDTD)	Finite-difference discretization of differential operators, Yee-grid, Courant stability criterion, numerical dispersion, perfectly matched layers, auxiliary field method for dispersive materials
Computer lab: Pulse propagation	Numerical and real dispersion, chirped pulses, pulse distortion, negative refraction
Day 9	
Computer lab: Simulation of ring resonator	Using RSoft Fullwave to obtain field distribution and transmission characteristics, Optimization
Day 10	
Lecture: Operator exponential techniques	Formal solution of first order differential equations through operator exponentials, evaluating the exponential of a matrix, Maxwell-Bloch equations and other coupled systems
Computer lab:	Simulation and visualization of radiation dynamics, modified

TECHNICAL MODULE: Computer Aided Design of Optical and Photonic Systems	
Parts of the course	**Content (selected keywords)**
Spontaneous emission in complex photonic systems	spontaneous emission rate, non-Markovian dynamics

2.3.6 Digital Signal Processing

This technical module will provide insight into the theory and practice of modern signal processing techniques. It will introduce (or refresh) the fundamentals of system theory and estimation theory. Numerous applications from a wide spectrum of signals from optical systems will illustrate the lectures. Laboratory experiments conducted by small groups of Ph.D. students will provide in-depth experience in selected fields of optical measurements and image processing. This technical module will be supplemented by lab tours in which the Ph.D. students experience applications at ongoing project work conducted by different groups at the Universität Karlsruhe (TH).

TECHNICAL MODULE: Digital Signal Processing	
Parts of the course	**Content (selected keywords)**
Day 1	
Lecture: digitization	System theory: Analogue and digital signals, sampling, quantization, interpolation
Lecture: introduction to linear and non-linear filters	Simple LTI-filters, correlation functions, matched filter, adaptive filters, rank filters, applications to the processing of optical measurements and images
Introduction to the lab	Presentation of the introductory problem: Noise suppression in optical measurement signals. First experiments with representation and visualization of digital signals
Day 2	
Lecture: Acquisition principles of optical signals	Fundamentals of signal acquisition of cameras, range cameras, laser scanners
Lab work:	Introductory problem: Noise suppression for various signals
Day 3-5	

TECHNICAL MODULE: Digital Signal Processing	
Parts of the course	**Content (selected keywords)**
Lecture: Object detection	Estimation theory: 3D reconstruction, object description, feature extraction, LS and robust estimation, tracking techniques
Lab work:	Problem: Object detection and tracking in images
Day 6 to 9	
Lab work:	Object detection and tracking in images
Day 10	
Lab tours	Applications of digital signal processing: signal enhancement and restoration, machine vision, autonomous mobile agents

2.4 Scientific Modules

The active participation in international scientific summer schools (e.g., NATO, CFN, Wilhelm and Else Heraeus Foundation, different universities and organizations) is encouraged and will be financed by KSOP. The immersion into the international scientific community is an integral part of a Ph.D. work and fosters the generation of international networks. We will also offer a KSOP summer school every second year. This event will be mainly managed by the graduate students and will strengthen the international contacts of the students and their ability for team-oriented project work. In addition, depending on their backgrounds and interests, students may be advised to attend specific lecture courses (or parts thereof) from the KSOP masters program.

2.5 Management Modules

The main outcome of a Ph.D. thesis has to be an in-depth and excellent scientific work. However, already during the Ph.D. work many students are facing management challenges. Project management and scheduling is a prominent example of a general management skill which is also needed in science. No experiment is free of constraints in resources and time. Furthermore, a major part of the graduates of our Ph.D. program will continue their career paths in industry and they will be directly immersed into a harsh business environment. The preparation for this challenge is not sufficient in our current Ph.D. education. Based on the modules that have been worked out for the HECTOR School of Engineering and

Management, we will offer a modular program for the KSOP Ph.D. students. The following two-week management modules will be offered:

Project Management (HECTOR School)	Human Resource Management (HECTOR School)
Project Management and Scheduling	Innovation Management
Information and Process Engineering	Teamwork and Creativity Generation
Multiproject Management in a Global Environment	Leadership and Conflict Management
Development Management	Management Training

2.5.1 Project Management

Project management and scheduling is a key to the world of business. In order to become fully acquainted with this important discipline, the course gives an introduction to project management and aims to help the participants to understand the objectives of project management and scheduling, to learn how to analyze planned projects and to control project execution. Particular attention is paid to the construction of project networks and Gantt charts, heuristic solution procedures and rescheduling as well as the completion of temporal and resource-constrained project scheduling computations. Modeling, planning and scheduling, which arise in a great variety of practical situations, are also emphasized. The course **Information and process modeling** provides a basic understanding of the major concepts in this significant field. Key questions regarding the objectives of modeling, entity-relationship modeling and the requirements of modeling languages are addressed. With regards to the question of modeling languages, all participants will learn the unified modeling language (UML) and web modeling languages, amongst others, and their specific application in the domain of business processes and information systems engineering. The modeling techniques of event driven process chains and Petri nets are also taught. Finally, and of utmost importance in the sphere of business administration, participants will directly apply the acquired modeling processes to different business cases through the use of case studies. **Multiproject management in a global environment** provides tools for future managers in all fields. The objective of this course is to familiarize participants with all aspects of this important domain, introducing methods and tools for a qualified and systematic approach when managing multiple projects, particularly focusing on a global setting. In the introductory lectures for this course participants will learn the definition of multiproject management and how to classify multiprojects. Fundamentals of corporate governance in an international business environment are also covered. After having learnt the basics, participants will begin to plan multiprojects in a global environment. In order to do this, forms of cooperation, organization and contract will be taught, and participants will also use tools and methods for multiproject and risk management and team creation in international environments. Once all of the planning stages have been covered, participants will begin the execution of multiprojects. Key issues to this are cost controlling and appointment controlling, knowledge of working progress, engineering performance, production hours, availability and reliability, risks and opportunities. Throughout all the stages industrial examples from international companies are discussed and reference is made to theoretical methods. **Development management** is an essential function in many industries and an in depth knowledge within this field is extremely advantageous. In partaking in this course participants will learn a definition and characterization of development itself. The significance of the processes, which make a product and a company successful, will also be taught. Through this, participants will gain insight into the influences on targets, methods of control development processes, cost and time management, human resource management, quality management and information management. In addition, fundamental methods, such as the adaptation of phase models, the strategic planning of human resources and the integration of a development department into a company will be taught. Real examples will be presented in order to convey company structures, project management and the influence of company-specific factors, three key issues within development management.

2.5.2 Human Resource Management

Innovation management is an important issue for industries, universities and companies alike. Whether the innovation focus is on new products, services, or business models the key is to find the best ideas and get those ideas into the marketplace as quickly as possible to achieve maximum results. First, the participants are introduced to the basics of innovation management. Thereafter, the focus is on innovation competition, strategic analysis of branches, companies and markets, product analysis, the innovation trap, strategies against the innovation trap, support of information in companies, core team management, internal process of product development, revitalization and adaptive design. R&D management is the next issue. The topics international R&D-management, enterprise strategy and innovation management, strategic prioritization of ideas and concepts, innovation pre-studies and feasibility studies, risk management and management of innovation processes are covered. Finally, important concepts of innovation, growth and employment, patent management and intellectual property, trademarks and standardization, and high technology concepts and export success are discussed. Upon finishing the course, participants will be fully aware of innovation processes and be able to integrate these processes into those of product development. **Teamwork and creativity generation:** Problem solving and decision-making can be performed by either an individual or a team. In this course participants will become familiar with the principals of team leadership and coaching, whilst recognizing the benefits of quality decision-making in multi-disciplined teams. Participants will learn the various types of teams and the skills of team leadership, such as increasing team identity and confidence, defining team targets and rules and structuring and preparing team meetings. The team meetings themselves are a fundamental part of the course as they improve participants' communication and teach how to give feedback and resolve any conflicts that may arise within the team. **Leadership of conflict management:** The aim of this course is to teach the fundamentals of professionals at work. In order to reach this target, participants will become acquainted with the basic concepts of leadership methods and learn techniques of managing stressful situations between employees on a daily basis. The course deals with agreements on objectives, management techniques in planning, communication and information, decision-making, leadership and teamwork, self-management, conflict resolution and conflict strategy. The use of several case studies reinforces all of these skills and introduces participants to the real-life application of leadership techniques in conflict management. **Management training:** Thorough knowledge in the field of management is essential for the career success. By focusing upon various company objectives and strategies participants will expand their knowledge of numerous aspects within the field of management. Particular emphasis is placed upon product life cycles, including the product's launch, entry into a new market and re-launch. The fundamental management techniques of competition analysis, portfolio analysis, marketing mix and pricing of special commercial operations are acquired in order to ensure product success. Participants will also become acquainted with and make use of breakeven analysis and market research reports as a way of making marketing decisions.

2.6 Working Groups

Much of the difficulties during a Ph.D. work are due to detailed instrumental and/or software problems. Typically, many of these problems have already been solved at other institutes or are currently being solved somewhere else. We will actively encourage students to form instrument user or software user working groups to foster progress. We expect each Ph.D. student to actively contribute to at least one of these working groups. Examples for possible working groups are:

- Use of CCD-cameras
- Use of optics and photonics design software packages
- Image and data processing
- Vacuum and thin-film deposition technologies
- Laser technology

3 Supervision and Mentoring

We believe that a well balanced system consisting of advice from supervising professors, mentoring with more experienced young scientists as well as the exchange of knowledge with peers provides the best ground for successful research work.

3.1 Ph.D. Student Advisors

Each Ph.D. student will have interdisciplinary thesis advice and cross-links provided by two thesis advisors preferably from two different departments. Regular meetings of both advisors and the doctoral student will ensure a rapid progress and a successful thesis completion during three years.

3.2 Mentoring

For each of the different specialization directions, a postdoctoral/young scientist mentoring system will be implemented. The mentor becomes active in the case of personal problems. She/he supports networking of the Ph.D. students and organizes social events, such as, e.g., excursions and alumni meetings. Through monthly meetings with the Ph.D. students, the mentor supports the technical and personal development of the student. The Ph.D. students are mentored by the young scientists who will act as coordinators of the four research areas.