Weitere Vorlesungen in Bezug auf Quantenelektronik: Uebersicht und Empfehlungen

Status Jan. 2019, Ursula Keller

IQE Master Kernfächer:

Quantum Optics

Ultrafast Laser Physics

Quantum Information Processing

Zusätzliche Vorlesungen (mit IQE Profs):

Modern Topics in Terahertz Science

Ultrafast Methods in Solid State Physics

Optical properties of semiconductors

Intersubband optoelectronics

Quantum Optics with Photonic Crystals, Plasmonics and Metamaterials

Nanomaterials for Photonics

Experimental Methods in Electro and Quantum Optics

Advanced Quantum Optics

Cavity QED and Ion Trap Physics

Experimental and Theoretical Aspects of Quantum Gases

Quantum optics with photonic crystals, plasmonics and metamaterials

Zusätzliche Vorlesungen (D-PHYS):

Ultrafast Processes in Solids

Zusätzliche Vorlesungen (andere Departemente):

Crystal Optics with Intense Light Sources

Nano-Optics

Nonlinear Optics

Optical Communication Fundamentals

Introduction to chemical reaction kinetics

Advanced kinetics

Quantum Optics

Fall Semester (offered every year - Kernfach)
3V + 2U

Lecturers: T. Esslinger, J. Faist, J. Home, A. Imamoglu

Kurzbeschreibung:
This course gives an introduction to the fundamental concepts of Quantum Optics and will highlight state-of-the-art developments in this rapidly evolving discipline. The topics covered include the quantum nature of light and photon statistics, optical coherent control of matter, strong light-matter interactions, laser cooling and atom trapping, Rydberg atoms, optomechanics.

Lernziel:
The course aims to provide the knowledge necessary for pursuing research in the field of Quantum Optics. Fundamental concepts and techniques of Quantum Optics will be linked to modern experimental research. During the course the students should acquire the capability to understand currently published research in the field.

Inhalt:
This course gives an introduction to the fundamental concepts of Quantum Optics and will highlight state-of-the-art developments in this rapidly evolving discipline. The topics which are covered include the quantum nature of light, atom-light interaction and quantum information processing. The course is based on selected text book chapters and original lecture notes. Specific topics include: Light-matter interaction and quantized fields, density matrix and Bloch equations, non-linear optics in the few photons limit, photon correlations, laser cooling, atom trapping, Rydberg atoms and photon blockade, optomechanics.

Ultrafast Laser Physics

Fall Semester (offered every year - Kernfach)
3V + 2U

Lecturers: L. Gallmann, S. Johnson, U. Keller

Kurzbeschreibung:
This course gives an introduction to ultrafast laser physics with an outlook in cutting edge research topics such as attosecond science and coherent ultrafast sources from THz to X-rays. Over the last decades ultrafast laser technology has made enormous progress, opening and enabling a large variety of new interdisciplinary research areas and many new applications. Examples include frequency combs for high-precision frequency metrology, high-harmonic generation as source of extreme ultraviolet light and attosecond pulses, terahertz pulse generation, optical communication, and laser material processing.

Lernziel:
The goal is to understand the basics for pursuing research and development in ultrafast laser science and technology. Fundamental concepts and techniques will be linked to a selection of hot topics in current research and applications.

Inhalt:
Linear pulse propagation, dispersion compensation, nonlinear pulse propagation (Kerr effect, self-phase modulation, self-focusing, filamentation, pulse compression, soliton pulses, nonlinear Schrödinger equation, delayed Raman response), second-order nonlinearities with short pulses (second harmonic and sum frequency generation, parametric amplification), laser pulse generation (relaxation oscillations, Q-switching, active and passive modelocking, saturable absorbers, KLM, SESAM), pulse characterization (fast electronics, autocorrelation, SPIDER, FROG), ultrafast spectroscopy (pump-probe measurements, electro-optic sampling, transient absorption), noise (amplitude and timing jitter), frequency combs and carrier envelope offset phase, high-harmonic generation and attosecond science, terahertz pulse generation and applications.

Quantum Information Processing (jointly offered with ITP & LFKP)

Spring Semester (offered every year - Kernfach)
3V + 2U

Lecturers: T. Esslinger, J. Home, A. Imamoglu, R. Renner, A. Wallraff

Kurzbeschreibung:
The course is an introduction to quantum information processing. It covers the basic theory of quantum information and quantum computation as well as experimental aspects.

Lernziel:
The goal is to acquire a good understanding of the ideas underlying quantum information processing. The course is also a preparation for subsequent more specialised courses in the area of quantum information science.

Inhalt:
The course starts with a treatment of key features of quantum theory that are relevant for information processing (such as quantum entanglement and non-locality). It covers basic communication tasks (quantum teleportation, entanglement swapping, key distribution, and distributed computation) as well as models of computation (e.g., the gate model) and algorithms (Deutsch-Jozsa and Shor). Further core topics are decoherence, quantum error correction, and fault tolerant quantum computation.

Voraussetzungen:
Quantum Mechanics I

Modern Topics in Terahertz Science

Fall Semester (offered every other year)
2V + 1U

Lecturer: S. Johnson

Kurzbeschreibung:
This course reviews current research topics in Terahertz Science with a strong focus on scientific applications in physics, chemistry and biology, as well as the emerging field of nonlinear THz optics.

Lernziel:
Terahertz frequency electromagnetic radiation lies at the border between electronics and optics, and as such has many unique properties that make it well-suited to study the electronic, magnetic and structural properties of many materials. The course objective is to give students the ability to identify problems of current interest in physics, chemistry, materials science and biology that can be potentially addressed using terahertz photonics and to design potential experimental solutions.

The course will focus predominantly on understanding research conducted over the last 4-5 years at the forefront of this developing field, with a strong emphasis on nonlinear THz science which has only recently become possible. This in particular has generated excitement as it offers potential new ways to control chemical reactions and/or phase transitons in materials.

Inhalt:
Topics to be discussed in the class include:

1) Overview of THz & interactions with matter
2) THz generation and detection
3) Linear THz spectroscopies
4) Imaging
5) Nonlinear THz interactions

Ultrafast Methods in Solid-State Physics

Spring Semester (offered every year)

Lecturers: S. Johnson, M. Savoini

Kurzbeschreibung:
This course provides an overview of experimental methods and techniques used to study dynamical processes in solids. Many processes in solids happen on a picosecond to femtosecond time scale. In this course we discuss different methods to generate femtosecond photon pulses and measurement techniques adapted to time resolved experiments.

Lernziel:
The goal of the course is to enable students to identify and evaluate experimental methods to manipulate and measure the electronic, magnetic and structural properties of solids on the

fastest possible time scales. These "ultrafast methods" potentially lead both to an improved understanding of fundamental interactions in condensed matter and to applications in data storage, materials processing and solid-state computing.

Inhalt:
The topical course outline is as follows:

0. Introduction
Time scales in solids and technology
Time vs. frequency domain experiments
Pump-Probe technique

1. Ultrafast processes in solids, an overview
Electron gas
Lattice
Spin system

2. Ultrafast optical-frequency methods
Ultrafast laser sources
Broadband techniques
Harmonic generation, optical parametric amplification
Fluorescence
2-D Spectroscopies

3. THz-frequency methods
Mid-IR and THz interactions with solids
Difference frequency mixing
Optical rectification

4. Ultrafast VUV and x-ray frequency methods
Synchrotron based sources
Free electron lasers
Higher harmonic generation based sources
Photoemission spectroscopy
Time resolved X-ray microscopy
Coherent imaging

5. Electron spectroscopy in the time domain

Optical properties of semiconductors

Fall Semester (offered every year)
2V + 2U

Lecturers: J. Faist and A. Imamoglu

Kurzbeschreibung:
This course presents a comprehensive discussion of optical processes in semiconductors.
Lernziel:

The rich physics of the optical properties of semiconductors, as well as the advanced processing available on these material, enabled numerous applications (lasers, LEDs and solar cells) as well as the realization of new physical concepts. The lecture aims at presenting both the fundamental theoretical and experimental concepts at the heart of the new development of the field.

Inhalt:
Electronic states in III-V materials and quantum structures, optical transitions, excitons and polaritons, carrier dynamics, novel two dimensional semiconductors such as graphene and transition metal dichalcogenides, spin-orbit interaction and magneto-optics.

Voraussetzungen:
Quantum Mechanics I, Solid State Physics I

Intersubband optoelectronics

Fall semester (offered every other year)
2V + 1U

Lecturer: J. Faist, G. Scalari

Kurzbeschreibung:
This course focuses on devices such as quantum cascade lasers and detectors in the THz and mid-infrared based on intersubband transitions in quantum heterostructures.

Lernziel:
The course aims to provide the knowledge necessary for pursuing advanced research in the field of quantum cascade lasers and the new generation of mid-infrared and terahertz solid-state devices.

Inhalt:
This lectures discusses the physics of the confined structures (band structures models, light-matter interaction, scattering rates, optical waveguides) as well as the device physics aspects such noise, dynamical behavior, mode-locking and comb operation.

Voraussetzungen:
Quantum Mechanics I, Quantum Electronics

Quantum Optics with Photonic Crystals, Plasmonics and Metamaterials

Spring semester (offered almost every year)
2V + 1U

Lecturer: J. Faist, G. Scalari

Kurzbeschreibung:
This course focuses on the study of quantum optics in solid-state cavities such as the ones created by photonic crystals, plasmonic structures as well as by metamaterials.

Lernziel:

The course aims to discuss the physics of light-matter interaction in solid-state cavities, providing both the core experimental and theoretical aspects.

Inhalt:
The field of quantum optics has been enriched by two relatively recent capabilities: on one hand the possibility to make optical cavities where the photon lifetime is extremely long, on the other hand subwavelength cavities in which the strength of the photon-matter coupling is extremely enhanced. In the first part of the lecture, we will discuss the physics and design of the cavities as well as their optimization. The second part of the lecture will be devoted to the so-called weak coupling regime, in which photon emission and detection are enhanced while the last part is dedicated to the strong and ultra-strong light-matter coupling regime. Scientific topics are Purcell effect, field enhancement, micro lasers, single photon emitters, cavity polaritons, Dicke phase transition.

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Voraussetzungen:
Quantum Mechanics I, Quantum Electronics

Nanomaterials for Photonics

Spring Semester (offered every year)
2V + 1U

Lecturer: R. Grange

Kurzbeschreibung:
The lecture describes various types of nanomaterials (semiconductor, metal, dielectric, carbon-based as nanotubes or graphene) for photonic applications (optoelectronics, plasmonics, photonic crystal, …). It starts with nanophotonic concepts of light-matter interactions, then the synthesis/fabrication methods, the optical characterization techniques and the applications.

Lernziel:
The students will acquire theoretical and experimental knowledge in the different types of nanomaterials for advanced applications in photonics. This multidisciplinary lecture will start with nanophotonics concept of light-matter interactions; then the various synthesis methods (top-down, bottom-up, …), the characterization techniques (SEM, TEM, STED, SNOM, …) and the applications (lab-on-a-chip devices, nanofluidic, nanomarkers for bioimaging…).

Inhalt:
Nanophotonics concepts of matter and radiation confinement, fabrication of nanomaterials, near-field and far-field characterization methods, plasmonics, organic nanomaterials (graphene), quantum dots, photonic crystals, nanomarkers.

Voraussetzungen:
Solid State Physics I

Experimental Methods in Electro and Quantum Optics

Spring Semester (offered intermittently)
2V + 1U

Lecturer: J. Home

Kurzbeschreibung:
We will cover experimental issues in making measurements in modern physics experiments. The primary challenge in any measurement is achieving good signal to noise. We will cover areas such as optical propagation, electronics, noise limits and feedback control. Methods for stabilizing frequencies and intensities of laser systems will also be described.

Lernziel:
This lecture aims to provide a background in the physics of many of the principal devices which are met in modern optics laboratories. In all of these system, considerations of amplification of signal vs the amount of noise introduced is of great importance. To deal with issues of stability and control, approaches which border on engineering are often found, including feedback control and electronics.

Inhalt:
The course will cover a number of different areas of experimental physics, including
Optical elements and propagation
Electronics and Electronic Noise
Optical Detection
Control Theory

Advanced Quantum Optics

Spring Semester (offered every other year)
2V + 1U

Lecturer: A. Imamoglu

Kurzbeschreibung:
This course builds up on the material covered in the Quantum Optics course. The emphasis will be on quantum optics in condensed-matter systems.

Lernziel:
The course aims to provide the knowledge necessary for pursuing advanced research in the field of Quantum Optics in condensed matter systems. Fundamental concepts and techniques of Quantum Optics will be linked to experimental research.

Inhalt:
Description of open quantum systems using master equation and quantum trajectories. Decoherence and quantum measurements. Dicke superradiance. Dissipative phase transitions. Spin photonics. Signatures of electron-phonon and electron-electron interactions in optical response.

Voraussetzungen:
Quantum Mechanics I, Quantum Optics

Cavity QED and Ion Trap Physics

Spring Semester
2V + 1U

Lecturer: J. Home, D. Kienzler

Kurzbeschreibung:
This course covers the physics of systems where harmonic oscillators are coupled to spin systems. Experimental realizations include photons trapped in high-finesse cavities and ions trapped by electro-magnetic fields. These approaches have achieved an extraordinary level of control and provide leading technologies for quantum information processing.

Lernziel:
The objective is to provide a basis for understanding the wide range of research currently being performed on fundamental quantum mechanics with spin-spring systems, including cavity-QED and ion traps. During the course students would expect to gain an understanding of the current frontier of research in these areas, and the challenges which must be overcome to make further advances. This should provide a solid background for tackling recently published research in these fields, including experimental realisations of quantum information processing.

Inhalt:
Cavity QED (atoms/spins coupled to a quantized field mode), Ion trap (charged atoms coupled to a quantized motional mode), Quantum state engineering: Coherent and squeezed states, Entangled states, Schrodinger's cat states, Decoherence (including): The quantum optical master equation, Monte-Carlo wavefunction, Quantum measurements, Entanglement and decoherence Applications: Quantum information processing, Quantum sensing.

Experimental and Theoretical Aspects of Quantum Gases

Spring Semester
2V + 1U

Lecturers: T. Donner, S. Huber, T. Esslinger

Kurzbeschreibung:
Quantum Gases are the most precisely controlled many-body systems in physics. This provides a unique interface between theory and experiment, which allows addressing fundamental concepts and long-standing questions. This course is jointly given by an experimentalist and a theorist and lays the foundation for the understanding of current research in this vibrant field.

Lernziel:
The lecture conveys a basic understanding for the current research on quantum gases. Emphasis will be put on the connection between theory and experimental observation. It will enable students to read and understand publications in this field.

Inhalt:

Cooling and trapping of neutral atoms
Bose and Fermi gases
Ultracold collisions
The Bose-condensed state
Elementary excitations
Vortices
Superfluidity
Interference and Correlations
Optical attices

Quantum optics with photonic crystals, plasmonics and metamaterials

Spring Semester
Lecturers: Giacomo Scalari and Jérôme Faist

In this lecture, we would like to review new developments in the emerging topic of quantum optics in very strongly confined structures, with an emphasis on sources and photon statistics as well as the coupling between optical and mechanical degrees of freedom.

1. Light confinement
   1.1. Photonic crystals
      1.1.1. Band structure
      1.1.2. Slow light and cavities
   1.2. Plasmonics
      1.2.1. Light confinement in metallic structures
      1.2.2. Metal optics and waveguides
      1.2.3. Graphene plasmonics
   1.3. Metamaterials
      1.3.1. Electric and magnetic response at optical frequencies
      1.3.2. Negative index, cloacking, left-handness
2. Light coupling in cavities
   2.1. Strong coupling
      2.1.1. Polariton formation
      2.1.2. Strong and ultra-strong coupling
   2.2. Strong coupling in microcavities
      2.2.1. Planar cavities, polariton condensation
   2.3. Polariton dots
      2.3.1. Microcavities
      2.3.2. Photonic crystals
      2.3.3. Metamaterial-based
3. Photon generation and statistics
   3.1. Purcell emitters
      3.1.1. Single photon sources
      3.1.2. THz emitters
   3.2. Microlasers
      3.2.1. Plasmonic lasers: where is the limit?
      3.2.2. $g^{(1)}$ and $g^{(2)}$ of microlasers
   3.3. Optomechanics
      3.3.1. Micro ring cavities
      3.3.2. Photonic crystals

3.3.3. Superconducting resonators

Ultrafast Processes in Solids
Fall Semester (offered every year)

Lecturers: Y. M. Acremann, A. Vaterlaus

Kurzbeschreibung:
Ultrafast processes in solids are of fundamental interest as well as relevant for modern technological applications. The dynamics of the lattice, the electron gas as well as the spin system of a solid are discussed. The focus is on time resolved experiments which provide insight into pico- and femtosecond dynamics.

Lernziel:
After attending this course you understand the dynamics of essential excitation processes which occur in solids and you have an overview over state of the art experimental techniques used to study fast processes.

Inhalt:
1. Experimental techniques, an overview

2. Dynamics of the electron gas
2.1 First experiments on electron dynamics and lattice heating
2.2 The finite lifetime of excited states
2.3 Detection of lifetime effects
2.4 Dynamical properties of reactions and adsorbents

3. Dynamics of the lattice
3.1 Phonons
3.2 Non-thermal melting

4. Dynamics of the spin system
4.1 Laser induced ultrafast demagnetization
4.2 Ultrafast spin currents generated by lasers
4.3 Landau-Lifschitz-Dynamics
4.4 Laser induced switching

5. Correlated materials

Related courses offered by other Departments

Crystal Optics with Intense Light Sources	
Possible lecturers	M. Fiebig
Frequency	1x year
Type of course	Specialized
Content	An introduction to polarization optics is given before optical properties following from crystal symmetry are discussed. Particular emphasis will be put on magneto-optical properties of crystals. Lasers as prototypical intense light sources will be introduced before advanced topics such as the determination of magnetic structures and interactions by nonlinear magneto-optics are discussed. Because of their aesthetic nature crystals are termed "flowers of mineral kingdom". The aesthetic aspect is closely related to the symmetry of the crystals which in turn determines their optical properties. It is the purpose of this course to stimulate the understanding of these relations. Particular emphasis will be put on the optical properties of crystals exposed to intense light fields (laser light), on nonlinear crystal-optical phenomena, and on optical properties related to ferroic order.
Nano-Optics	
Possible lecturers	L. Novotny
Frequency	1x year
Type of course	Specialized
Content	Nano-Optics is the study of optical phenomena and techniques on the nanometer scale. It is an emerging field of study motivated by the rapid advance of nanoscience and technology. It embraces topics such as plasmonics, optical antennas, optical trapping and manipulation, and high-resolution imaging and spectroscopy. Controlling and engineering the light-matter interaction with suitably engineered nanostructures has applications in photodetection, light emission and sensing. Starting with an angular spectrum representation of optical fields the role of inhomogeneous evanescent fields is discussed. Among the topics are: theory of strongly focused light, point spread functions, resolution criteria, confocal microscopy, and near-field optical microscopy. Further topics are: optical interactions between nanoparticles, atomic decay rates in inhomogeneous environments, single molecule spectroscopy, light forces and optical trapping, photonic bandgap materials, and theoretical methods in nano-optics.
Nonlinear Optics	
Possible lecturers	J. Leuthold
Frequency	1x year
Type of course	Specialized

Content	Nonlinear optics deals with the response of material to light and the mathematical framework to describe the phenomena. This lecture is aimed at giving a fundamental understanding to such effects as the refractive index, the electro-optic effect, second harmonic generation, four-wave mixing and scattering. The lecture starts with a classification of the various nonlinear optical effects encountered in nature. We then discuss the various properties within the framework offered by the nonliner susceptibilities of order 1, 2 and 3. Finally, the lecture gives an overview on nonlinearities found in crystals, in semiconductors and in fibers.
Optical Communications Fundamentals	
Possible lecturers	J. Leuthold
Frequency	1x year
Type of course	Specialized
Content	Optics has changed the way we communicate and has led to a thriving new optical industry offering many opportunities. This lecture begins by introducing communication basics and optical communication concepts such as: the “Shannon Law” and other fundamental concepts. The lecture then proceeds with the most important optoelectronic components (transmitter, receiver, switches, amplifiers,…) and the optical fiber. The lecture further discusses how a bit is encoded, processed, received and how bit-error ratios are determined. Towards this goal we also review fundamental noise sources such as the shot-noise, the thermal noise and the amplifier noise. Finally, we discuss some powerful digital signal processing tools that are frequently used to estimate and undo errors.
Introduction to chemical reaction kinetics	
Possible lecturers	F. Merkt
Frequency	1x year
Type of course	Specialized
Content	Fundamental concepts: rate laws, elementary reactions and composite reactions, molecularity, reaction order. Experimental methods in reaction kinetics: time-resolved spectroscopy (from attoseconds to seconds), relaxation methods, crossed-beam techniques. Simple chemical reaction rate theories. Reaction mechanisms and complex kinetic systems, approximation techniques, chain reactions, explosions and detonations. Homogeneous catalysis and enzyme kinetics.
Advanced kinetics	
Possible lecturers	H. J. Wörner, J. Richardson
Frequency	1x year
Type of course	Specialized
Content	Advanced experimental methods of reaction kinetics (with time resolved X-ray, UV-VIS, IR, EPR and NMR spectroscopy). Theory of molecular quantum dynamics, reactive scattering and chemical reactions. Kinetic studies of primary processes in simple and

	complex systems on time scales from attoseconds to seconds. Fundamentals of electrochemical kinetics: electron transfer, elementary processes, electrocatalysis.