Optics and Optoelectronics

Coordinated by: Department of Chemical Physics and Optics

Study programme coordinator: prof. RNDr. Petr Malý, DrSc.

Characterization of the study programme:

The program is offered to students who want to gain a broader physical perspective and detailed knowledge as well as practical skills needed for scientific and research activities in the field of optics and optolelectronics. The course prepares students for both independent creative activity and teamwork. The obtained broader overview also creates preconditions for work in interdisciplinary areas at the interface of physics, biology and technical fields. Emphasis is placed on high professionalism in optics and optoelectronics with good knowledge of computer technology. The student chooses one of two specializations according to his/her interest and the topic of his/her diploma thesis. The specialization Quantum and nonlinear optics focuses mainly on the properties of optical fields within classical and quantum optics, on nonlinear optical phenomena and on methods of laser spectroscopy. The specialization Optoelectronics and photonics deals in detail with the interaction of light with solids, with light detection, and with semiconductor technology for optoelectronics and photonics applications. Part of the study plan in both specializations is practical teaching conducted in laboratories equipped at the current world level, which ensures the competencies of graduates in the field of experimental research, optical spectroscopy, applied optics, optoelectronics and spintronics. Elective courses cover emerging fields in the world such as opto-spintronics, physics for metamaterials and terahertz spectroscopy. The extension of optics into a number of fields (physics, biology, chemistry, and medicine) and its ever-increasing applications in everyday life increase the adaptability of graduates and the possibilities of their application in scientific science and in practice. Graduates are fully prepared for further doctoral studies in the Czech Republic and abroad.

Profile of the graduates and aims of the study:

The graduate has deep theoretical and experimental knowledge of classical and quantum optics and optoelectronics. Masters mathematical modelling of physical processes in optics and optoelectronics. He is able to apply this knowledge and skills in research and scientific activities in the fields of optics, optoelectronics, spintronics, photonics, laser physics, statistical and coherence optics, nonlinear optics, optical communication and information processing, instrumental optics, and in many fields where optics or optical spectroscopy is used (biology, chemistry, medicine). Physical education combined with the acquisition of skills in the field of computer programming, information technology and the organization of team scientific work increases the possibilities of employment at universities and scientific institutes as well as in industry. The graduate is able to communicate professionally in Czech and English and has experience with the preparation and design of grant projects and the organization of scientific work. He is ready for further doctoral studies or scientific and pedagogical activities at universities and scientific institutes in the Czech Republic and abroad. Graduates can also be employed as research and development workers or managers in private companies and institutions.

Recommended plan of the study

A pre-requisite of the study in this program is knowledge of wave optics and fundamentals of optical spectroscopy on the Bachelor level.

Compulsory and compulsory-optional courses

The student chooses one of two specializations: Quantum and nonlinear optics, Optoelectronics and photonics. Due to the different requirements for the oral part of the final state examination, it is recommended to choose the subjects of the profiling basis within the elective subjects as follows: for specialization Quantum and Nonlinear Optics subjects Quantum Optics I, Quantum Optics II, Integrated and fibre optics, and for specialization Optoelectronics and photonics subjects Physics of Semiconductors for optoelectronics II, Physics of Semiconductors for optoelectronics III, Electron transport in Quantum Systems.

First year of the Master study

Code	Subject	Credits	Winter	Summer
NOOE002	**Semiconductor Physics for Optoelectronics I**	3	2/0 Ex	—
NOOE003	**Materials and Technology in Optoelectronics**	3	2/0 Ex	—
NOOE046	**Special Practical Course in Optics and Optoelectronics I**	6	0/4 MC	—
NFPL182	**Solid State Theory**	9	4/2 C+Ex	—
NOOE027	**Introduction to Quantum and Nonlinear Optics I**	6	3/1 C+Ex	—
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NOOE016	**Special Practical Course in Optics and Optoelectronics II**	6	—	0/4 MC
NOOE072	**Theory of spatial symmetry in systems for optics**	3	—	2/0 Ex
NOOE028	**Introduction to Quantum and Nonlinear Optics II**	6	—	3/1 C+Ex
NBCM067	Quantum Optics I [1]	5	2/1 C+Ex	—
NBCM093	Quantum Optics II [1]	5	—	2/1 C+Ex
NBCM096	Electron Transport in Quantum Systems [2]	5	—	2/1 C+Ex
NOOE008	Semiconductor Physics for Optoelectronics II [2]	3	—	2/0 Ex

[1] Recommended for specialization Quantum and Nonlinear Optics.
[2] Recommended for specialization Optoelectronics and Photonics.

Second year of the Master study

Code	Subject	Credits	Winter	Summer
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NOOE061	**Nonlinear Optics of Semiconductor Nanostructures**	5	2/1 C+Ex	—

NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NOOE005	Semiconductor Physics for Optoelectronics III [2]	5	2/1 C+Ex	—
NOOE007	Integrated and Fibre Optics [1]	3	2/0 Ex	—
NOOE034	Laser Theory	3	2/0 Ex	—
NOOE026	Ultrashort Laser Pulses	3	2/0 Ex	—
NOOE033	Special Seminar on Quantum and Nonlinear Optics [1]	3	0/2 C	0/2 C
NOOE010	Special Seminar on Optoelectronics [2]	3	0/2 C	0/2 C

[1] Recommended for specialization Quantum and Nonlinear Optics.
[2] Recommended for specialization Optoelectronics and Photonics.

Compulsory-optional courses – group 2 (15 credits)

Code	Subject	Credits	Winter	Summer
NBCM067	Quantum Optics I	5	2/1 C+Ex	—
NBCM096	Electron Transport in Quantum Systems	5	—	2/1 C+Ex
NOOE008	Semiconductor Physics for Optoelectronics II	3	—	2/0 Ex
NBCM093	Quantum Optics II	5	—	2/1 C+Ex
NOOE005	Semiconductor Physics for Optoelectronics III	5	2/1 C+Ex	—
NOOE007	Integrated and Fibre Optics	3	2/0 Ex	—
NOOE034	Laser Theory	3	2/0 Ex	—
NOOE026	Ultrashort Laser Pulses	3	2/0 Ex	—
NOOE033	Special Seminar on Quantum and Nonlinear Optics	3	0/2 C	0/2 C
NOOE010	Special Seminar on Optoelectronics	3	0/2 C	0/2 C
NOOE035	Luminescence Spectroscopy of Semiconductors	3	2/0 Ex	—
NOOE029	Microcavities	3	2/0 Ex	—
NOOE127	Nanooptics	3	2/0 Ex	—
NOOE123	Optics of periodic structures for photonics	3	2/0 Ex	—
NOOE120	Optical Spectroscopy in Spintronics	3	—	2/0 Ex
NOOE025	Ultrafast laser spectroscopy	3	2/0 Ex	—

Recommended optional courses

Code	Subject	Credits	Winter	Summer
NBCM101	*Detection and Spectroscopy of Single Molecules*	3	2/0 Ex	—
NOOE124	*Photonic structures and electromagnetic metamaterials*	3	2/0 Ex	—
NOOE047	*Integrated Optics*	3	2/0 Ex	—
NOOE113	*Laser Metrology*	3	2/0 Ex	—

NFPL004	*Nonequilibrium Statistical Physics and Thermodynamics*	3	2/0 Ex	—
NBCM305	*Optical Sensors*	3	2/0 Ex	—
NOOE074	*Magneto-optics theory*	3	2/0 Ex	—
NOOE133	*Topological properties of light and matter*	3	2/0 Ex	—
NBCM102	*Fundamentals of Classical Radiometry and Photometry*	3	2/0 Ex	—
NOOE048	*Fundamentals of Design and Production of Optical Components*	1	0/1 C	—
NOOE119	*Nonlinear Optical Spectroscopy*	3	—	2/0 Ex
NOOE011	*Optics of Thin Films and Multilayers*	3	—	2/0 Ex
NOOE130	*X-Ray Lasers and X-Ray Optics*	3	—	2/0 Ex
NOOE015	*Seminar*	2	—	0/1 C
NOOE125	*Spectroscopy in the terahertz spectral range*	3	—	2/0 Ex
NOOE073	*Contemporary Microscopy*	3	2/0 Ex	2/0 Ex
NOOE126	*Seminar of Femtosecond Laser Spectroscopy*	2	0/2 C	0/2 C
NBCM323	*Seminar on open quantum system theory*	1	0/1 C	0/1 C

Conditions that must be satisfied to register for the state final exam

– gain of at least 120 credits
– passing all compulsory courses
– gain of at least 31 credits from compulsory-optional courses
– submission of the completed diploma thesis within the given deadline

The final state examination consists of two parts:

I Defence of the diploma thesis
II Oral part

Knowledge requirements for the oral part

Note: Student is asked two questions from part A and one question from part B in accord with the student‘s specialization.

A Common requirements

1. Advanced quantum mechanics, quantum theory of solid state

Role of symmetry in physics, eigenstates and their degeneration. Selection rules of physical processes in atoms, molecules and solids. Problem of many particles in quantum theory. Atoms and molecules. Electronic and vibration properties of solids. Second quantization. Quantization of electromagnetic field. Interaction of atom with electromagnetic radiation. Basics of relativistic quantum theory of electron. Single-electron approximation in solid state quantum theory, Blochś theorem, Brillouin zones. Influence of translation symmetry breaking, Wannierś theorem, superlattices and quantum structures. Thermodynamics and statistical physics of elementary excitations. Electron transport in electric and magnetic fields. Dielectric properties of solids. Quasiparticles in solids.

2. Wave optics, basics of quantum and nonlinear optics

Light as electromagnetic waves. Polarization of light, its mathematical description. Optical constants, Kramers-Kroning relations. Phenomena on interface between media. Light waves in absorbing medium. Complex representation of light waves. Wave theory of optical coherence. Scalar diffraction theory. Fourier optics and holography. Gaussian beams, other types of light beams. Optical resonators. Propagation of light in waveguides, optical fibres. Light-matter interaction, classical and semi classical theory. Dynamical properties of laser. Laser types. Linear and nonlinear optics. Nonlinear phenomena of the second order. Nonlinear phenomena of the third order. Spontaneous and stimulated scattering. Nonstationary coherent phenomena.

3. Basics of physics and technology of semiconductors for optoelectronics

Semiconductor materials and their parameters. Phase equilibria. Crystal growth. Crystal defects. Impurities in crystals. Passivation and metallization of surfaces. Preparation of single crystals and thin films. Electrons, holes, band structure of bulk semiconductors. Drift, diffusion, generation, recombination, capture and tunnelling of charge carriers. Low-dimensional semiconductor structures. Linear and nonlinear optical properties of semiconductors and their nanostructures.

4. Experimental methods

Methods for measuring the properties of optical radiation. Measurement of light beam parameters. Sources and detectors of optical radiation. Spectroscopic instruments. Methods for measuring the optical constants of materials. Spectroscopic methods for investigating materials according to the type of interaction. Basic experiments of classical and quantum optics.

B Specializations

Quantum and Nonlinear Optics

1. Quantum Optics

Electromagnetic field quantization. Photon, coherent and thermal states of field. Interaction of light with matter. Spontaneous, stimulated emission and absorption. Lifetime, shape of spectral line. Interaction of an atom with coherent light. Bloch's equations. Reduced density matrix. Relaxation in open systems, master equation, stochastic quantum dynamics. Kubo's response theory. Field correlation of the first and second order, Mach-Zender and a Hanbury Brown-Twiss interferometers. Beam splitters. Multimode light. Continuous frequency and time representation. Photon echo. Einstein-Podolsky-Rosen paradox. Entangled states. Quantum cryptography and teleportation. Methods of quantum description of laser, rate equations. Fluctuations in quantum systems, laser stability, output field statistics. Quantum description of nonlinear optical processes.

2. Integrated and quantum optics

Optics of interfaces, thin films and multilayers. Matrix description of light propagation in layered structures. Periodic structures. Fundamentals of photonic crystal theory. Silicon photonics. Photonic band structure. Microcavities. Methods for characterization of waveguide structures. Fundamentals of technology for integrated optics. Passive structures and dynamic components of integrated optics. Optical wave propagation in waveguides, modes. Characteristics of waveguides. Coupling elements for optical waveguides. Cylindrical dielectric waveguide. Single-mode and multimode optical fibres. Application of structures of integrated photonics in optical communication, information technology and sensors.

3. Methods of optical spectroscopy

Optical absorption and luminescence spectroscopy. Luminescence spectroscopy of semiconductors. Study of properties of electrons, excitons, photons, impurity states. Strong excitation effects. Stimulated emission in semiconductors and their nanostructures. Ways of generation and detection of spin-polarized charge carriers. Optical spectroscopy methods for the study of spin-polarized carriers in semiconductors. Properties of ultrashort laser pulses and their propagation. Methods of ultrafast spectroscopy.

Optoelectronics and photonics

1. Semiconductor physics for optoelectronics

Methods of excitation of charge carriers in semiconductors. Recombination of charge carriers in semiconductors. Radiative and non-radiative transitions. Hot carriers, relaxation. Photoconductivity by inhomogeneous excitation. Surface states, surface conductivity and recombination. P-N transition and its characteristics. Schottky contact, basic approaches to charge transport. Structure MIS. Heterogeneous transitions. Low-dimensional semiconductor structures, electronic states in quantum lattices, wires and dots. Photovoltaic phenomena, irradiated P-N junction, irradiated Schottky contact.

2. Optical and transport properties of semiconductors and their nanostructures

Dispersion relations and general properties of optical constants. Kramers-Kronig relations. Quantum theory of optical transitions. Interband transitions. Allowed and forbidden, direct and indirect transitions. Impurity absorption. Reflection in the area of lattice oscillations. Non-perturbative description of interactions in the crystal, quasiparticles (phonon, plasmon, exciton, polariton). Free electron model. Plasma edge. Interband recombination. Stimulated emission. Low-dimensional semiconductor structures, their optical properties, magnetotransport and resonant tunnelling. Classical, semi classical and quantum-mechanical description of electron transport. Aharon-Bohm effect. Resonant tunneling and Coulomb blockade. Quantum Hall effect. Spintronics.

3. Optoelectronic and photonic elements

Semiconductor sources of optical radiation. Electroluminescent layers, light emitting diodes. Semiconductor lasers. Quantum cascade lasers. Semiconductor detectors, factors affecting detectivity. Photoresistors, photodiodes, avalanche photodiodes, phototransistors. Semiconductor sensors. Vidicon, charge-coupled device. Photovoltaic cells. Structures of integrated optics. Microresonators, silicon photonics. Photonic mirrors, waveguides, fibres, resonators, optical filters, elements based on negative index of refraction. Plasmonic structures.