

DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Center	Department
Solid State Physics (10 ECTS credits)	Physics N 002	Center for Physical Sciences and Technology	Optoelectronics Department
Student's workload	Hours	Student's workload	Hours
Lectures	40	Consultations	
Individual study	200	Seminars	10

Course annotation

The course aims at presenting an integral and systematic description of the physical properties of crystalline solids at the doctoral-studies level.

The course develops the microscopic description of solids starting from crystal structure and symmetry and proceeding through electronic structure, semiconductor physics, charge-carrier dynamics, lattice vibrations, and thermal phenomena. Particular attention is given to the relation between microscopic quantum-mechanical models and experimentally observable properties of solids. The main topics of the course (and their approximate content): Crystal structure and crystallography (long-range order and periodicity, translation and point symmetry, Bravais lattices, primitive and Wigner–Seitz cells, point groups, classification of crystals, Miller indices, characteristic ionic, metallic, and covalent crystal structures). Crystallophysics and reciprocal space (tensors of physical quantities, coordinate transformations, Neumann principle, stress and strain, reciprocal lattice, crystallographic planes, Brillouin zones, Fourier representation of periodic structures). Diffraction in crystals (X-ray diffraction, Laue equations and diffraction conditions, Bragg law, reciprocal-space interpretation of diffraction and principal experimental diffraction techniques). Microscopic description and chemical bonding in solids (many-particle Schrödinger equation, adiabatic/Born–Oppenheimer approximation, static-lattice approximation, interatomic interaction, ionic, covalent, metallic, and van der Waals bonding). Single-particle description of the electronic system (Hartree, Hartree–Fock and density-functional approaches, exchange interaction, quasiparticles and the jellium approximation). Electron gas in solids (Boltzmann and Fermi gases, Fermi–Dirac statistics, density of states, Fermi energy, Sommerfeld description, electron correlations, Wigner crystallization and screening of the Coulomb interaction, including Debye–Hückel, Thomas–Fermi and Lindhard approaches). Electronic band structure (Bloch theorem, Brillouin-zone reduction, Kronig–Penney model, tight-binding and nearly-free-electron approximations, Wannier functions and Fermi surfaces). Methods of band-structure analysis (cellular, APW, OPW, KKR, pseudopotential and LMTO methods, $\mathbf{k} \cdot \mathbf{p}$ approach, effective mass, Kane and Luttinger models, semiconductor band structures). Electron dynamics in external fields (quasiclassical/WKB equations of motion, effective-mass and envelope-function approximations, Wannier description, electrons and holes). Semiconductors (electronic structure of elemental and compound semiconductors, shallow and deep impurities, impurity states, carrier statistics, heavily doped semiconductors and the insulator-to-metal transition). Electric- and magnetic-field phenomena (electrical conductivity, drift velocity, mobility, Bloch oscillations, classical carrier motion in magnetic fields, Hall effect, magnetoresistance, Landau quantization, spin splitting, magnetization and de Haas–van Alphen oscillations). Phonons and lattice dynamics (harmonic approximation, normal vibrations, one-dimensional monoatomic and diatomic chains, acoustic and optical phonons, quantization of lattice vibrations, infrared-active optical phonons and polaritons, three-dimensional lattice dynamics, dynamical matrix,

polarization vectors, Bose–Einstein statistics and the elastic-continuum description of acoustic phonons). Heat capacity of solids (Dulong–Petit law, Einstein and Debye models, low- and high-temperature limits and electron and phonon contributions to heat capacity). Experimental investigation of phonon spectra (infrared spectroscopy, inelastic neutron scattering, Raman and Brillouin scattering, acousto-optical effects and ballistic phonon imaging). Anharmonic effects and thermal transport (thermal expansion, Grüneisen theory, phonon–phonon interaction, selection rules, normal and Umklapp processes, phonon and electron contributions to thermal conductivity, isotope scattering and boundary-limited phonon transport).

List of literature

1. N. W. Ashcroft and N. D. Mermin, Solid State Physics (Holt, Rinehart and Winston, 1976).
2. P. Y. Yu and M. Cardona, Fundamentals of Semiconductors (Springer, 2002).
3. Lecture notes

Consulting teachers	Scientific degree	Pedagogical Name	Main scientific works published in a scientific field in last 5 year period
Andrea Zelioli	Dr.		1. A. Zelioli, A. Špokas, B. Čechavičius, M. Talaikis, S. Stanionytė, V. Bukauskas, A. Vaitkevičius, A. Čerškus, P. Wojnar, V. Deibuk, E. Dudutienė, R. Butkutė, Comprehensive investigation of emission homogeneity of InGaAs multiple quantum wells using spatially resolved spectroscopy, Sci. Rep. 15, 32885 (2025). 2. A. Štaupienė, A. Zelioli, A. Špokas, A. Vaitkevičius, B. Čechavičius, S. Stanionytė, S. Raišys, R. Butkutė, E. Dudutienė, Internal quantum efficiency of GaAsBi MQW structure for the active region of VECSELs, Appl. Phys. Lett. 125, 221102 (2024). 3. A. Štaupienė, M. Jokubauskaitė, A. Zelioli, A. Špokas, M. Skapas, B. Čechavičius, R. Butkutė, E. Dudutienė, Improving optical properties through growth temperatures and post-growth annealing in parabolic GaAsBi/AlGaAs quantum wells, J. Alloys Compd. 1060, 187230 (2026). 4. A. Vaitkevičius, A. Špokas, A. Zelioli, U. Cibulskaitė, A. Bičiūnas, E. Dudutienė, B. Čechavičius, M. Skapas, A. Čerškus, M. Talaikis, P. Baranowski, P. Wojnar, R. Butkutė, Segregation-driven formation of bismuth quantum dots in parabolic GaAsBi/AlGaAs quantum structures, Surf. Interfaces 68, 106586 (2025). 5. A. Zelioli, J. Žuvelis, U. Cibulskaitė, A. Špokas, E. Dudutienė, A. Vaitkevičius, S. Stanionytė, B. Čechavičius, R. Butkutė, Optimization of AlGaAs barrier for InGaAs

			quantum wells emitting in the near infrared, Lith. J. Phys. 64(4), 244–252 (2024). 6. A. Špokas, A. Zelioli, A. Bičiūnas, B. Čechavičius, J. Glemža, S. Pralgauskaitė, M. Kamarauskas, V. Bukauskas, J. Spigulis, Y.-J. Chiu, J. Matukas, R. Butkutė, Optimising (Al,Ga)(As,Bi) quantum well laser structures for reflectance mode pulse oximetry, Micromachines 16, 506 (2025). 7. I. Pliaterytė, L. Dundulis, J. Glemža, S. Pralgauskaitė, J. Matukas, A. Špokas, A. Zelioli, M. Kamarauskas, A. Bičiūnas, B. Čechavičius, R. Butkutė, Low Frequency Noise Spectroscopy of GaAsBi QW Structures for NIR Light Sources, Fluct. Noise Lett., 2640004 (2026).
Certified during the Doctoral Committee session on 29/09/2026, protocol No. 5.2.2 E-15600-KT-3702			
Committee Chairman prof. Jūras Banys			